

# ASTRONOMY<sup>®</sup>

***Venus: An Earth Gone Wrong?***  
***How to Make Great Astro-Slides***  
***ASTRONOMY Field Tests the OR-840***

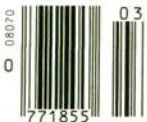
March 1990 U.S. \$2.50  
U.K. £1.60  
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ICD 08070



80#

***Southern Sky Spectacular: Eta Carinae***





# New Meade® Premier Series™: The

Plug into 8,199 objects with the Meade CAT Computer Aided Telescope system.

Meade 8" 2080/Model 50. (Shown with DRS.)

Meade 10" 2120/Model 50H with Superwedge.

Collects 56% more light than 8" models.

Multi-function, hand-held Electronic Command Center (ECC) is included with, or available for, all Premier Series models.

## MEADE PREMIER SERIES 8" AND

| Model          | Aperture | f/Ratio | Drive | Wedge      | Tripod | Finder         | Diagonal | Eyepieces | Accessories <sup>1</sup> |
|----------------|----------|---------|-------|------------|--------|----------------|----------|-----------|--------------------------|
| 2080/Model 30  | 8"       | f/10    | LX6   | Standard   | Field  | 6 x 30mm       | 1.25"    | MA 25mm   | Package A                |
| 2120/Model 30  | 10"      | f/10    | LX6   | Standard   | Field  | 8 x 50mm       | 1.25"    | MA 25mm   | Package A                |
| 2120/Model 30H | 10"      | f/10    | LX6   | Superwedge | Field  | 8 x 50mm       | 1.25"    | MA 25mm   | Package A                |
| 2080/Model 36  | 8"       | f/6.3   | LX6   | Standard   | Field  | 6 x 30mm       | 1.25"    | MA 25mm   | Package A                |
| 2120/Model 36  | 10"      | f/6.3   | LX6   | Standard   | Field  | 8 x 50mm       | 1.25"    | MA 25mm   | Package A                |
| 2120/Model 36H | 10"      | f/6.3   | LX6   | Superwedge | Field  | 8 x 50mm       | 1.25"    | MA 25mm   | Package A                |
| 2080/Model 50  | 8"       | f/10    | LX6   | Standard   | Field  | 9 x 60mm Polar | 2"       | SP 26mm   | Package A                |
| 2120/Model 50  | 10"      | f/10    | LX6   | Standard   | Field  | 9 x 60mm Polar | 2"       | SP 26mm   | Package A                |
| 2120/Model 50H | 10"      | f/10    | LX6   | Superwedge | Field  | 9 x 60mm Polar | 2"       | SP 26mm   | Package A                |
| 2080/Model 56  | 8"       | f/6.3   | LX6   | Standard   | Field  | 9 x 60mm Polar | 2"       | SP 26mm   | Package A                |
| 2120/Model 56  | 10"      | f/6.3   | LX6   | Standard   | Field  | 9 x 60mm Polar | 2"       | SP 26mm   | Package A                |
| 2120/Model 56H | 10"      | f/6.3   | LX6   | Superwedge | Field  | 9 x 60mm Polar | 2"       | SP 26mm   | Package A                |
| 2080/Model 70  | 8"       | f/10    | LX6   | Standard   | Field  | 9 x 60mm Polar | 2"       | Package B | Packages A & C           |
| 2120/Model 70H | 10"      | f/10    | LX6   | Superwedge | Field  | 9 x 60mm Polar | 2"       | Package B | Packages A & C           |
| 2080/Model 76  | 8"       | f/6.3   | LX6   | Standard   | Field  | 9 x 60mm Polar | 2"       | Package B | Packages A & C           |
| 2120/Model 76H | 10"      | f/6.3   | LX6   | Superwedge | Field  | 9 x 60mm Polar | 2"       | Package B | Packages A & C           |

<sup>1</sup>Package A: 115v AC and 12v DC power cords; battery pack. Package B: SP 26mm; SWA 40mm; UWA 6.7mm; UWA 14mm. Package C: #1200 Electric Focuser; Off-Axis

## ...Buy Now and Receive \$1000 in Meade

\$1000 Coupon offer is valid at participating dealers in the U.S. and Canada.

Now, for a limited time, you can save \$1000 on the purchase of important Meade photo-visual accessories when you buy a Meade 8" or 10" Schmidt-Cassegrain telescope. Here's how it works:

1. Buy any Meade 8" or 10" SCT model—LX3, LX5, LX6, Premier Series, or Standard 2080—from your participating Meade dealer, between January 1 and March 31, 1990.
2. Packed with your telescope you will receive a booklet of coupons which are as good as cash towards the purchase of a wide range of Meade accessories.
3. Submit one or more of the coupons to the dealer from whom you purchased the telescope, and subtract the value of the coupon from your dealer's best price for the accessories you wish to purchase.





# Integrated SCT System...

Meade Premier Series 8" and 10" Schmidt-Cassegrains let you buy according to your requirements and budget now, without sacrificing any upgrade capability in the future. Purchase the 8" 2080/Model 30 today, and add the hand-held Electronic Command Center, Digital Readout System, CAT Computer Aided Telescope system, or Electric Declination Motor at any later date—and know that all of these important options integrate readily into the Premier system.

Or, if you're ready for a more advanced instrument now, consider the features and extra value that one of the Meade 50- or 70-series models represents. Either way, you'll be assured of buying a telescope that will not become obsolete

as your interests expand. *All Premier Series telescopes include the following standard equipment:*

■ **f/6.3 or f/10 Diffraction-Limited Optics**—Legendary *hand-matched*, laser-tested optical quality that has made Meade Instruments the World's leading, and largest, manufacturer of Schmidt-Cassegrain telescopes. No other manufacturer offers you a choice of either wide-field f/6.3 or classical f/10 optics to suit your applications. Meade 10" models collect 56% more light than 8" models, at modest additional cost.

■ **LX6 Drive System and Power Panel**—The most sophisticated and precise drive system ever offered on a com-

mercial telescope. Includes quartz micro-processor-controlled drive electronics, multi-function display panel, and outlet jacks for available electronic options listed in the table below. The motor drive runs from either 115v AC outlets, or, for field use, from 12v DC auto cigarette lighter plugs.

■ **Multi-Coated Optics**—Enhanced coatings on all mirror and lens surfaces that optimize light transmission through the telescope.

■ **Field Tripod, Wedge, Finderscope, and Accessories**—All Premier models are supplied as complete instruments, ready to set up and operate.

## 10" SCHMIDT-CASSEGRAINS

| ECC <sup>2</sup> | EDM <sup>3</sup> | CAT <sup>4</sup> | DRS <sup>5</sup> | Remarks                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------|------------------|------------------|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Optional         | Optional         | Optional         | Optional         | <i>The lowest-cost, fully-upgradable Schmidt-Cassegrains available from any manufacturer.</i> 30-series SCT's combine f/10 optical systems and the industry's finest motor drive system. "H" models include Superwedge for extreme stability during long-exposure astrophotography.                                                                                                                                                                      |
| Optional         | Optional         | Optional         | Optional         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Optional         | Optional         | Optional         | Optional         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Optional         | Optional         | Optional         | Optional         | <i>The lowest-cost f/6.3 Schmidt-Cassegrain ever!</i> Meade f/6.3 models reduce astrophoto exposure times by 60% compared to f/10 models. Eyepiece for eyepiece, images are 2½ times brighter and fields of view 59% wider.                                                                                                                                                                                                                              |
| Optional         | Optional         | Optional         | Optional         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Optional         | Optional         | Optional         | Optional         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Standard         | Standard         | Optional         | Optional         | 50-series models include hand-held Electronic Command Center and Electric Declination Motor for full dual-axis electronic control of the telescope. Use the 2X speed for precise corrections during astrophotography; flip to 8X speed for image centering and field scanning.                                                                                                                                                                           |
| Standard         | Standard         | Optional         | Optional         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Standard         | Standard         | Optional         | Optional         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Standard         | Standard         | Optional         | Optional         | Identical to 50-series in specifications, including dual-axis Electronic Command Center, but with fast, wide-field f/6.3 optical system. 2" multi-coated diagonal mirror permits use of wide-angle 2"-barrel eyepieces as well as standard 1.25"-barrel eyepieces.                                                                                                                                                                                       |
| Standard         | Standard         | Optional         | Optional         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Standard         | Standard         | Optional         | Optional         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Standard         | Standard         | Standard         | Standard         | Meade 70- and 76-series are the most advanced and fully-equipped instruments of their types currently available. Included is virtually every accessory required for a lifetime of advanced photo and visual observing: the CAT Computer Aided Telescope system with its 8,199-object memory; Off-Axis Guider/Illuminated Reticle Eyepiece assembly for long-exposure astrophotography; an assortment of 4 superb eyepieces; and #1200A electric focuser. |
| Standard         | Standard         | Standard         | Standard         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Standard         | Standard         | Standard         | Standard         |                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

Guider; MA 12mm Illuminated Reticle Eyepiece. <sup>2</sup>Electronic Command Center. <sup>3</sup>Electric Declination Motor System. <sup>4</sup>Computer Aided Telescope System. <sup>5</sup>Digital Readout System.

## Accessory Coupons!

Accessories available under this special offer include all of the premium Meade photo-visual options that are in greatest demand:

**CAT Computer Aided Telescope System**—The computerized celestial navigation system that enables the finding of 8,199 objects in seconds. **Save \$200.**

**Digital Readout System**—Read out celestial coordinates quickly and precisely. **Save \$100.**

**Series 4000 Eyepieces**—The World's finest oculars for your telescope. **Save \$15 to \$25** on Super Plössls; **\$25 to \$50** on Super Wide Angles; **\$40** on Ultra Wide Angles.

**Plus: Save \$10 to \$100** on 10 other valuable Meade accessories, from T-Adapters and Off-Axis Guiders to Nebular Filters

and Electric Focusers. *Call or visit your Meade dealer today for further details!*

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### Meade Catalog package #90C—\$3.00

Includes 4 separate catalogs and bulletins on the entire range of Meade astronomical telescopes, Series 4000 eyepieces, and accessories.

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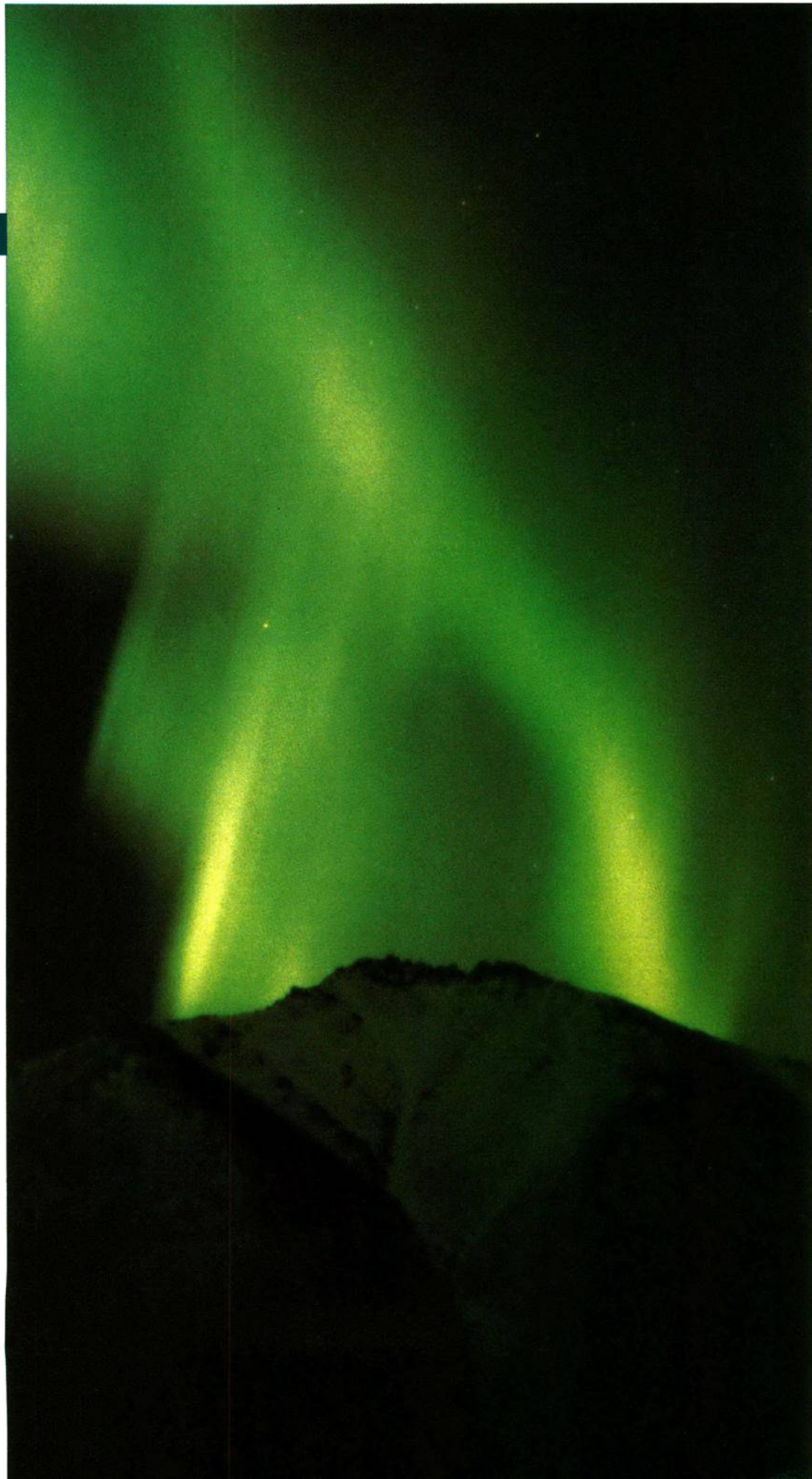
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**ON THE COVER:**

The intricate Eta Carinae Nebula is one of the southern sky's deep-sky showpieces. (See page 72.) Cerro Tololo Inter-American Observatory photo.

**IT'S CURTAINS** for aurora observers during this period of increased solar activity. Photo by Forrest Baldwin.





# ASTRONOMY®

March 1990

Vol. 18, No. 3

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## SEEKING SIGHTS UNSEEN

With far-seeing telescopes, far-reaching spaceprobes, and questioning minds, astronomers epitomize human curiosity. As amateurs and as professionals in the field of stargazing, we want to see, to know, and to experience what's around the next bend, over the next hill, beyond the next range of mountains — to worlds beyond our vision.

The stories in *ASTRONOMY* this month explore remote worlds and places we can never see. We explore the surface of Venus, discuss the deep interior of the Sun, and take an imaginary ride on a beam of light that left a quasar 12 billion years ago at a time when the universe was young. We also have a story about the wonders of the Southern Hemisphere sky — glories that too few of us northern types have had the pleasure of seeing.

We go to Venus with Stephen Saunders, project scientist for the *Magellan* mission. Earlier spacecraft have shown us enough that we know Venus is unlike Earth, but not enough for us to know what Venus is really like. Altimetry maps, low-resolution radar images, and a few brief glimpses of the surface constitute our whole picture.

We also explore the most unreachable place in the solar system: the Sun's core. Astrophysicist John Bahcall guides us through the strange world of neutrino astronomy and tells us why we're searching for the Sun's secrets in a place forever hidden from view.

Our imaginary ride from a distant quasar is a journey through time as well as space. Through Earth-based telescopes we form images with light billions of years old. The vast scale of the universe bars us from seeing what that quasar looks like today; we can see only what it once was.

By comparison, the southern sky is much more accessible. For the price of a plane ticket to Australia or Peru, you can see the star-rich 30 percent of the sky that's invisible from North America. Your guide to the southern wonders is Gregg Thompson, an Australian who recently traveled north to see exotic constellations like Ursa Major and Cassiopeia that are, from Australia, permanently hidden from view.

In a magazine it's easy to travel to places far, far away. The power of words, images, and our imaginations instantly leap the countless light-years. The restraints of time have no hold. We gaze in wonder at all we see.

Sincerely,



Richard Berry  
Editor-in-Chief

## ASTRONOMY

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### No More RTGs?

I read with interest Bruce Gagnon's letter regarding nuclear-powered equipment in space (September 1989). I suggest that Mr. Gagnon reread John Casani's Viewpoint in the June 1989 issue in which Mr. Casani supports nuclear power in space. Mr. Casani made a clear distinction between the use of nuclear powered, Earth-orbiting reactors and RTGs for interplanetary space exploration.

As a member of the Planetary Society, a professional in the news media, and a subscriber to *ASTRONOMY* for more than ten years, I have never heard of an instance when an RTG has posed any threat to anyone. The RTGs aboard *Galileo* and many other spacecraft have been tested repeatedly for safety in the event of an accident.

I found Mr. Gagnon's claim that the military runs NASA hard to accept. Even so, I wish whoever is running the show in the United States and the Soviet Union would join hands for a joint mission to Mars. Why not use nuclear technology for this rather than funneling money into nuclear weapons on Earth? — *George Hammond-Burns, Berowra, New South Wales, Australia*

### The Battle against Light

I have a neighbor across the street who seems to need a light on round the clock. Their most bothersome light shines directly into a field I use for observing. The light is positioned so it shines almost horizontally — not straight down. I have asked them to turn the light off or at least aim it toward the ground. This usually works for a month or two, then I'm back where I started. What can I do? — *Jeff L. Wills, Holliston, Massachusetts*

— *We suggest friendly persuasion as the best answer to light-pollution woes. Perhaps a calm, in-depth explanation of why you need to have darkness to observe the sky might impress on their minds the importance of showing consideration to you. As an alternate strategy, why not invite the neighbors over to see some sights of the universe for themselves? This tactic often converts the worst grumps into people who can appreciate what you're doing and will no longer interfere.*

*As a final resort, there may be some legal recourse, depending on your state's interpretation of its laws. In 1989 a district court in Indiana ruled that a neighbor whose light interfered with an amateur astronomer had to shut off the*



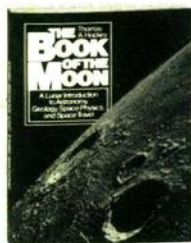
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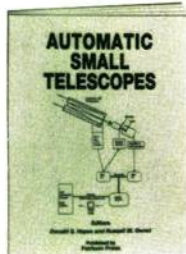
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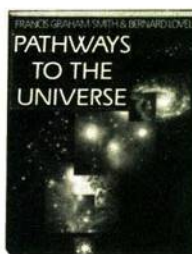
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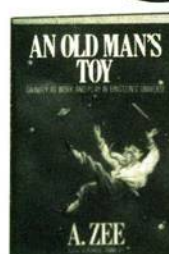
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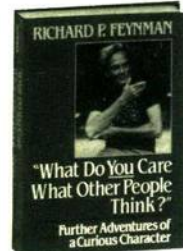
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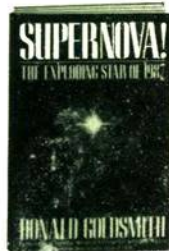
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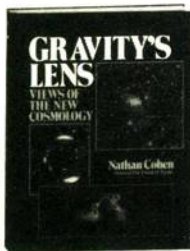
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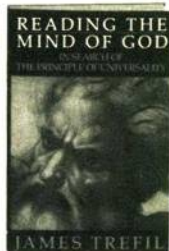
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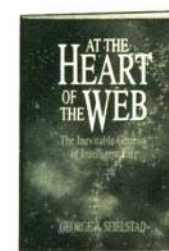
58576 \$14.95



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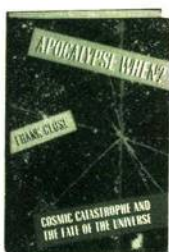
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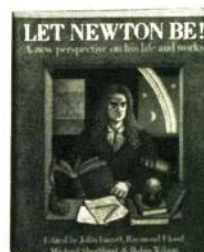
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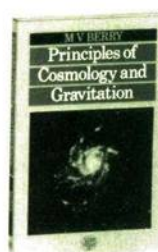
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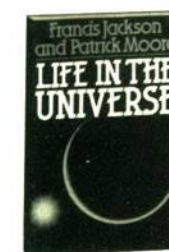
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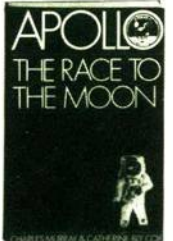
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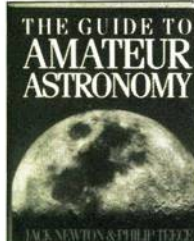
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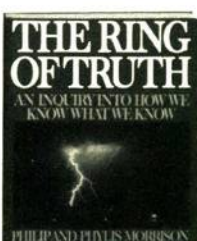
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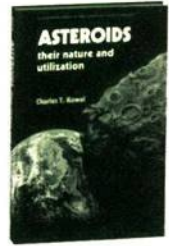
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Astronomy 3/90



light (*Amateur News*, July 1989). Before you investigate the legal possibilities in your state, however, try working it out yourself.

## Daytime Finder Scope Alignment

In your product test of the Meade 2120/LX6 telescope ("ASTRONOMY Tests the Meade 2120/LX6," December 1989), Robert Burnham noted that the LX6's manual does not explain how to align the finder scope with the main scope's optical axis. Mr. Burnham further stated that this needs to be fixed, and I couldn't agree more. While such procedures are easy for old timers, telescope manufacturers should be wise enough to include instructions that won't confuse first-time telescope users.

*The Summer Stargazer* by Robert Claiborne describes a nice method for daytime finder scope alignment. First, place a piece of automobile chrome or Christmas tree ornament one-quarter mile away to serve as a marker. Back at your telescope, center the shiny marker in your telescope's field of view. Gently snug up the screws on the finder scope's front ring and slowly adjust the screws on the rear ring, centering the marker in the finder's field of view. By going back and forth between the front and rear rings, increasing the magnification and the tension on the finder's screws each time, you can accurately align the finder scope in a few minutes. — *Mark Schnoor, Aberdeen, South Dakota*

## Correction

An editorial error appeared in the story "Unveiling the Hidden Milky Way" (November 1989). In the left column on page 37, the fifth sentence in the second paragraph should read: "The wavelength of the most commonly emitted photons, 2.6 millimeters, corresponds to the difference in energy between the carbon monoxide molecule's first rotational energy level and its lowest rotational energy level."

The photograph of galaxies M81 and M82 on page 4 of the January 1990 issue was taken by Larry Myers of Elk Grove, California, not by Tony Hallas and Daphne Mount. □

*ASTRONOMY welcomes comments, corrections, and additional information on articles and astronomy in general. Send your letters to: ASTRONOMY Letters, P. O. Box 1612, Waukesha, WI 53187. Letters may be edited for length or clarity.*

# ASTRONOMY IS FUN!

by Stephen Edberg  
former coordinator for amateur observations for the International Halley Watch, presently science coordinator for the Comet Rendezvous/Asteroid Flyby mission, and an incorrigible observer always.

Astronomy is fun. Everyone who does astronomy agrees. The problem is they disagree on what fun means. This has led to a continuing debate among amateur astronomers.

In recent years we've heard a lot about what amateur astronomers "should" be doing. Professional astro-

**Fun in astronomy  
is where you find it.  
There's room for  
all types of practitioners.**

mers (myself among them) have made considerable efforts to get amateurs to make scientifically useful observations. Some amateurs have even appealed to friends and colleagues to "get serious." But alongside the calls for scientific contributions a backlash has developed in defense of non-scientific observing.

The past twenty years have seen almost unbelievable technical changes in both amateur and professional astronomy. As telescopes have grown larger and more sophisticated, I hear owners praising their instruments' abilities but I also hear a curious silence about what they actually do with them. I think many observers are failing to push their old instruments to their limits and are not exploring the new vistas made possible with the new instruments. This seems a gross waste of telescopes, time, and especially talent when there are so many mysteries in the universe to explore, scientifically or not.

And yet I temper my professional's point of view when I reconnect with my amateur roots. Professionally, at the Jet Propulsion Laboratory, I'm involved in cometary research, in which I use observations by amateur astronomers and plan observations to be made by spacecraft. Yet I'm also an active amateur astronomer who usually makes observations scientifically, but sometimes not.

I went "pro" the summer after high school when I was hired as a solar observer at the High Altitude Observatory in Colorado. A benefit of my two decades working professionally in astronomy since then is that I have learned that being curious about the universe and discovering something not known before is enormous fun. Unexpectedly, I find my amateur interests have evolved. For example, I came to realize that the Sun was far more interesting than I had first thought. Also, my interests in transient astronomical phenomena such as meteors, lunar and planetary occultations, and eclipses have deepened.

I now try to contribute to astronomy as an amateur by timing occultations and recording data in the correct manner for good scientific results. But although I know well the value of scientific observations, I sometimes sky-watch just for the fun of it. I'm not alone — one well-known comet scientist said his plans for observing Halley's Comet included a six pack and a pair of binoculars.

Fun in amateur astronomy is where you find it. I enjoy talking to people about astronomy, especially elementary school kids, who have boundless curiosity and no inhibitions about asking questions. Learning from amateurs is what makes conventions and conferences fun for me. I attend meetings for the people, not the observing. It's my chance to learn new things as I walk around a field of telescopes or listen to a speaker.

The simple truth is there's room in astronomy for all types of practitioners. Recreational astronomy can be done scientifically or casually by the same person with lots of pleasure and without guilt. Astronomy is fun whether you practice it in an armchair, at the telescope, or at a public lecture or star party.

Don't close out the other side, though. It's well worth keeping your mind open to new things. If the feeling stirs you, branch out — learn a new observing technique or investigate a new aspect of astronomy. Push your telescope to new limits. It's astonishing how little extra effort it takes to change casual observations into scientifically useful ones. Grow and explore. The universe has plenty of mysteries and the more you know, the more you can wonder over and share. □





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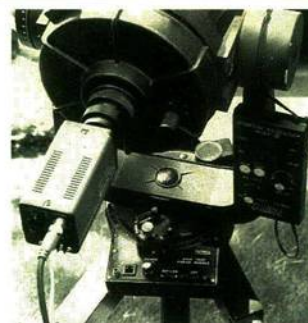
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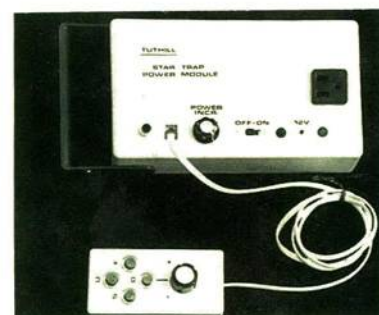
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## MOST-DISTANT QUASAR PROBES EARLY UNIVERSE

Astronomers working at Palomar Observatory have discovered a quasar in the constellation Ursa Major that is the most distant object in the universe. The quasar, designated PC 1158 +4635, is estimated to be 14 billion light-years away, corresponding to a time when the universe was only one billion years old and roughly one-sixth the size it is now.

The discovery was made by Donald P. Schneider of the Institute for Advanced Study in Princeton, New Jersey, Maarten Schmidt of Caltech (who, in 1963, showed that quasars are very distant and thus intrinsically very bright objects), and James E. Gunn of Princeton. For the past several years they have been conducting surveys for very distant quasars using the 200-inch Hale telescope. PC 1158 +4635 was first noted in a survey in February 1988. A detailed spectroscopic analysis was conducted a year later.

The quasar's carbon IV emission line — normally found at the ultraviolet end of the spectrum — was shifted 473 percent toward longer wavelengths. Thus its redshift is 4.73, which corresponds to a recessional velocity of 94 percent of the speed of light. The redshift of an astronomical object results from the expansion of the universe. As the distance between galaxies and quasars is stretched, the light rays traveling between them are also stretched to longer wavelengths and thus redder light. Objects at progressively greater distances have greater recessional velocities and redshifts.

The discovery of PC 1158 +4635 increases to eleven the number of quasars with redshifts greater than 4.00. The previous record was 4.43, held by a quasar discovered in September 1987. Despite the discoveries of these high-redshift quasars, the failure to find great numbers of them implies a cutoff at redshifts of about 4. Such a cutoff may represent the epoch when galaxies first formed.

"Since we believe quasars are associated with galaxies, then galactic-sized objects must have formed when the universe was very young," said Schneider. "If the age of the universe is 15 billion years, the redshift-4.73 quasar was emitting light just over 1 billion years after the Big Bang. This places some serious constraints on cosmological evolution that theories of galaxy formation



**NO MORE THAN A DOT** in this image, the redshift-4.73 quasar PC 1158 +4635 has significant cosmological implications. Photo courtesy of Donald P. Schneider.

must address."

The constraints Schneider refers to center largely on the time it took for galaxies to form after the Big Bang. The most successful galaxy formation model, called the cold dark-matter model, predicts that the first galaxies formed no earlier than a redshift of 5. Although the existence of a 4.73-redshift quasar does not strictly conflict with the cold dark-matter model, it implies that the quasar must have formed at an earlier epoch (higher redshift) because of the time needed for its first stars to form. It would take the discovery of several quasars at redshifts greater than 5 to disqualify the model.

High-redshift quasars may also provide insights into the transparency of the early universe. One surprising fact that Schneider, Schmidt, and Gunn discovered in their study of PC 1158 +4635 and other high-redshift quasars is that the intergalactic medium — the empty space between galaxies — has a "startling opacity" at redshifts above 4. At redshifts above 4.2, for example, nearly 60 percent of the energy emitted by quasars is absorbed by intergalactic matter, while only a quarter of the energy is absorbed at a redshift of 3.

Astronomers think the very early universe was a kind of radiant soup in which hydrogen atoms were ionized (stripped of their electrons) by the high temperature. Just as particulates in cloudy water scatter light, the free elec-

trons acted as particulates to scatter photons, making the universe opaque. The universe didn't clear up until 300,000 years after the Big Bang when the temperature dropped to about 3000 kelvins. At that time electrons could bind to hydrogen nuclei. With nothing to impede radiation, the universe became transparent.

The opacity revealed by PC 1158 +4635 points to a "cloudier" early universe. "We see more opacity than we have come to expect," said Gunn. "We may have gotten to the point where the intergalactic medium has not yet been completely ionized. What's important is that we may be seeing [back to the era] of this ionization."

### SEEING SHARP WITH ADAPTIVE OPTICS

A team of astronomers from the European Southern Observatory and the Paris Observatory has tested a new instrument that cancels the effects of atmospheric turbulence. The instrument uses a computer-controlled flexible "adaptive optics" mirror. With the adaptive optics system turned on, the images from the telescope are almost as sharp as if the telescope were in space.

Since the invention of the telescope in the early seventeenth century, astronomers have had to accept that the sharpness of astronomical images is limited by turbulence in the Earth's atmosphere. Turbulence breaks a star image into a multitude of moving sub-images. Seen in a telescope, the size of a stellar image is equal to the area within which this swarm of sub-images moves.

Because of this, the sharpest images attainable, even for large astronomical telescopes, are limited by the state of the atmosphere. Large telescopes are placed at sites where the atmospheric turbulence is as small as possible, for example, in the Andes Mountains.

The new instrument, called "Adaptive Optics Prototype 3," proved its ability to overcome turbulence during tests in mid-October 1989. With the instrument at the coudé focus of the 1.52-meter (60-inch) telescope at the Haute Provence Observatory in France, astronomers obtained stellar images that were limited in sharpness only by the telescope's aperture. Such performance is known as diffraction limited.



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results from *Ulysses*, and *Mars Observer*. The Planetary Society fought to keep these missions on track when they were threatened by budget cuts, launch vehicle cancellations and simple indifference. And we've become the first private organization to design actual hardware for a space venture—the Soviet Union's ambitious *Mars '94* mission. We invite you to join us.

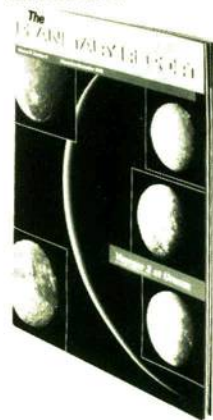
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## THE PLANETARY SOCIETY

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Adaptive optics systems work by correcting the atmospheric distortions of starlight after it passes through the telescope. Within the adaptive optics instrument a small computer-controlled deformable mirror changes its surface to compensate for the distortions starlight suffers in passing through the atmosphere. The adaptive optics mirror in the prototype has nineteen actuators, and the surface is corrected 100 times per second. A powerful computer calculates how the actuators located behind the deformable mirror should push or pull the deformable mirror. An optical wavefront sensor measures the shape of the distorted starlight, and supplies this information to the computer.

On each of ten nights, astronomers imaged ten bright stars through infrared filters. They made several exposures through each filter with the adaptive optics system off, followed immediately by an equal number with the system on. The exposures lasted from 10 to 100 seconds.

At infrared wavelengths of 3.5 micrometers and longer, the diffraction limited performance was always obtained irrespective of atmospheric turbulence. The diffraction limit was often reached at 2.2 micrometers, and a noticeable improvement in image quality was seen at 1.2 micrometers.

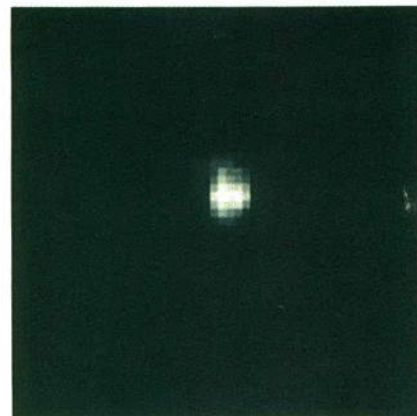
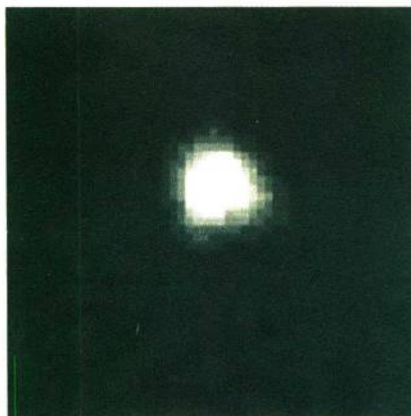
Adaptive optics complements telescopes with active optics, such as ESO's New Technology Telescope (Astro-News, August 1989). In active optics, a control system keeps large astronomical mirrors in optimal shape against the distortions of gravity, wind, and heat. Adaptive optics correct errors caused by atmospheric turbulence.

This new technology makes it possible to reach the theoretical limits of imaging in the infrared wavelength range with a medium-sized telescope. Astronomers will next aim at perfecting the technique for larger telescopes and at shorter wavelengths. The prototype adaptive optics instrument will next be installed at the European Southern Observatory 3.6-meter telescope at La Silla.

Not only will present-day telescopes benefit, but adaptive optics could revolutionize next-generation telescopes such as the European Southern Observatory's 16-meter Very Large Telescope.

### MIT LAUNCHES EDUCATION PROGRAM

The Massachusetts Institute of Technology has announced a new program



**DRAMATIC IMPROVEMENT** results from adaptive optics. Atmospheric turbulence smears a star image to 1.2 arcseconds (left). With adaptive optics, the star is 0.4 arcseconds in diameter. European Southern Observatory photo.

to promote astronomy education. Established at the urging of Congressman Chester Atkins of Massachusetts, the program will introduce young science students to professional astronomy through hands-on experience at the MIT's Haystack Observatory in Tyngsboro, Massachusetts.

The Haystack Educational Outreach Program will offer summer internships to middle-school students selected from the Fifth Congressional District in Massachusetts. MIT officials hope to enroll twenty students in the program in 1990 and twice that number by 1991.

The students will learn about the scientific work ongoing at Haystack Observatory, handle and process data from the observatory's radio telescopes, receive scientific materials and journals, and attend conferences at the observatory. Observatory staff members feel that the program is the best possible way to share the satisfaction and excitement of a career in astronomy.

### PLANETARY SOCIETY SCHOLARSHIPS AVAILABLE

The Planetary Society, a nonprofit group of space enthusiasts, has announced its 1990 scholarships in astronomy. Over the past four years the Society has awarded over \$50,000 in scholarships to outstanding high school and college students. This year over \$11,000 in scholarships is available.

Entrants must submit a 2,500 word essay on a relevant topic. Eligibility is limited to Planetary Society members pursuing a career in planetary science. Undergraduate students can apply for one of five \$1,000 grants. High school and college students can enter a contest to win \$1,000 plus a trip to a major Mars conference this summer.

For more information on the scholarship program, contact Scholarship Department, The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106.

## Space News

### IT'S A GO FOR CRAF/CASSINI

At long last NASA has won approval from Congress to begin a pair of new solar system missions that will explore Saturn and a comet. The Mariner Mark II program, consisting of the *Comet Rendezvous/Asteroid Flyby* (CRAF) mission and the Saturn-orbiting *Cassini* mission, received "new start" funding

totaling \$30 million in the fiscal 1990 budget approved by Congress last fall.

CRAF is scheduled for an August 1995 launch and a rendezvous with Comet Kopff five years later. *Cassini*, a joint NASA/European Space Agency mission, will lift off in April 1996 for a 2002 arrival at Saturn.



Although the Mark II program received its full budget request, Congress did place a stringent ceiling on total expenditures for the two spacecraft. If the budget "cap" is exceeded, Congress will require cuts in the program. "In the event that it is determined during the course of this program that the total budget will exceed \$1.6 billion," the appropriations bill states, "NASA will be required to descope the program.... If the descoping includes the cancellation of one of the missions, the mission to be cancelled is CRAFT."

Also receiving new start funding this year is the Search for Extraterrestrial Intelligence (SETI) program, which will scan the sky for artificially produced radio signals. NASA's largest new program, however, did not fair so well. Space Station *Freedom* received \$1.8 billion this year, \$250 million less than NASA had requested.

## SOLAR MAX PLUMMETS TO EARTH

The *Solar Maximum Mission* satellite plunged into the Indian Ocean on December 2, 1989, bringing to an end a decade-long mission devoted to studying the Sun. The fiery re-entry apparently went unseen by observers, and there were no reports that any pieces of the 5,000-pound spacecraft survived.

Ironically, the demise of *Solar Max* was hastened by the forces it was designed to study. The satellite was launched in February 1980 to observe the Sun as it neared the peak of its 11-year cycle of activity. But by 1989 the Sun was approaching another, even stronger peak in activity. As atomic particles spewed from solar flares and levels of ultraviolet radiation increased, Earth's atmosphere grew warmer and expanded. As a result, *Solar Max* experienced more atmospheric drag, which quickened its fall from orbit.

During its ten-year mission, *Solar Max* revolutionized our knowledge of the Sun. In addition to probing the inner workings of solar flares (the spacecraft observed over 12,500 of them), *Solar Max* determined for the first time that the Sun emits more energy near the time of sunspot maximum and less energy near sunspot minimum.

Among the spacecraft's other achievements, *Solar Max* made the first observations of gamma rays emitted by supernova 1987A, discovered comets crashing into the Sun, and studied Earth's eroding ozone layer.

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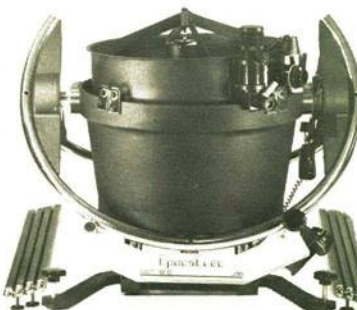
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1.25" Kellner Eyepieces-5mm #8536, 9mm #8538, 12mm #8540, 18mm #8508, 25mm #8510, 40mm #8512

\$33.95 ea. (1.89)

1.25" Orthoscopic Eyepieces-5mm #8500, 7mm #8502, 9mm #8504, 12.5mm #8506, 18mm #8524, 25mm #8526

\$49.95 ea. (1.89)



### Orion® Explorer Series .965" Eyepieces

Get the most from your small telescope with these fine fully-coated eyepieces. Standard .965" barrels fit all Japanese standard small telescopes.

.965" Orthoscopic Eyepieces-5mm #8580, 7mm #8581, 9mm #8582, 12.5mm #8583

Was \$42.95

Now \$36.95 ea. (1.89)

.965" Kellner Eyepieces-18mm #8584, 25mm #8585

Was \$32.95

Now \$24.95 ea. (1.89)



### Orion® 2" Multi-Coated Eyepieces

Excellent quality wide-field eyepieces

32mm Erfle 2" Eyepiece

#8492 \$99 (2.59)

50mm Plössl 2" Eyepiece-Offers the brightest, widest field. Preferred for faint celestial phenomena.

#8490 \$79 (2.59)



### Orion® 2" Star Diagonal

Get the widest possible field of view from your Schmidt-Cassegrain Telescope. This star diagonal features a special aluminized and overcoated first-surface 1/4-wave flat mirror.

#8767 \$89.95 (2.59)



### Quality, Affordable Orion® Barlow Lenses

Achromatic, fully coated 2-element lens system with finest machined aluminum construction. Ideal for reflector and refractor telescopes.

2x 1.25" Barlow Lens

#8744 \$39.95 (1.89)

2x .965" Barlow Lens

#8742 \$27.95 (1.89)



### Orion® Ultrascopic™ Eyepieces

Unlike other premium eyepieces, Orion Ultrascopics offer complete multi-layer coatings on ALL surfaces, for superior light transmission and contrast. Modern 5- and 7-element designs for pinpoint star images and breathtaking detail. Wide 52° field of view. Compare with other brands selling for much more!



#### Wide Field 5-element

35mm Ultrascopic #8560 \$99 (2.29)

30mm Ultrascopic #8562 \$89 (2.19)

25mm Ultrascopic #8564 \$79 (2.19)

#### Medium-High Power 5-element

20mm Ultrascopic #8566, 15mm Ultrascopic #8568

10mm Ultrascopic #8570, 7.5mm Ultrascopic #8572

\$74.95 ea. (2.19)

#### High Power 7-element

5.0mm Ultrascopic #8574, 3.8mm Ultrascopic #8576

\$87.50 ea. (2.19)

### Orion® MegaVista™ 1.25" Wide Angle Eyepieces

Incredible fully multi-coated high transmission 7-element eyepieces with integral rubber eyeguard and long eye-relief.

10.5mm-An incredible 67° field for outstanding planetary or deep space performance.

#8552 \$129 (2.29)

16.8mm-Outstanding high-contrast eyepiece with stunning 70° field ideal for deep space.

#8554 \$139 (2.29)



### Orion® UltraZoom™ 7-21mm 1.25" Eyepiece

The finest zoom you can buy for your 1.25" telescope. An excellent choice for astronomy or terrestrial observing. 65°-35° field.

#8556 Was \$149 \$129 (2.29)



### Orion® VariPower™ 2-3x Multi-Coated Barlow Lens

Our new variable barlow offers significant improvement over other models we've seen. The magnification is adjusted by sliding the internal lens cell along a calibrated scale (you don't have to poke a finger or pencil inside to do this). Fully Multi-Coated optics provide excellent sharpness, contrast and brightness. 1.25" diameter.

#8748 \$69.95 (2.19)



### Orion® Ultrascopic™ 3-element Fully Multi-Coated Barlow Lens

Fully Multi-Coated 3-Element Barlow lens provides superior imaging with precise color correction at three wavelengths. For maximum light transmission and highest contrast, we have used the finest quality multi-coating on each air to glass surface. 1.25" Diameter

#8750 Was \$69 Now \$59.95 (2.19)



### Orion® Deluxe Fully-Baffled Multi-Coated Barlow Lens

Fully internally baffled and baffled to block stray light for noticeably higher contrast. Larger 27mm multi-coated 2-element lens provides 2x magnification with any 1.25" eyepiece.

#8746 \$49.95 (2.09)



2450 17th Ave., P.O. Box 1158, Santa Cruz, CA 95061





# ORION TELESCOPE CENTER

## Astronomer's Choice

### Orion® Premium Off-Axis Guider

Use with any 1.25" illuminated Reticle Eyepiece. For Meade and Celestron Schmidt-Cassegrains.

#5144 **\$59.95** (1.69)



### World's Finest Illuminated Reticle Eyepiece

6mm Orthoscopic design for required high-power guiding, plus unique X-Y adjustable reticle positioning for easy guide-star alignment. Wireless LED illuminator has adjustable brightness.

#8487 Was \$149

Now **\$129** (2.69)



### Orion® 9mm Orthoscopic Illuminated Reticle Eyepiece

9mm Orthoscopic eyepiece with wireless adjustable brightness illuminator. Built-in eyewall with three concentric circles helps measure limits of acceptable guiding error.

#8488 **\$119** (2.69)



### Orion® 12mm Kellner Illuminated Reticle Eyepiece

12mm Kellner eyepiece with cable plugs into LX-3 and LX-5 drive bases, and most drive correctors with illuminated reticle output for polar alignment and guiding.

#8482 Was \$79

Now **\$69.95** (2.19)



### Orion® Universal Combined Camera Adapters

Combination Eyepiece Projection Tube and Prime Focus Adapter for refractors and reflectors with 1.25" eyepiece holders. Use with T-Ring (sold separately) to match your 35mm camera.

Standard Universal Camera Adapters

For .965" Eyepiece Holders #5258 **\$29.95** (1.89)

For 1.25" Eyepiece Holders #5254 **\$34.95** (1.89)

Variable Power Camera Adapter

Unique sliding barrel design allows variable projection distances during eyepiece projection photography, eliminating the need to change eyepieces when magnification changes are required.

#5262 Was \$49.95 Now **\$44.95** (1.89)



### Orion® T-Adapter

For prime focus photography. Use with T-ring to match your 35mm camera. For Meade, Celestron 8", 10" SC.

#5116 **\$27.95** (1.89)



### Orion® Tele-Extenders

For high powered photography with your Meade, Celestron 8", 10" Schmidt-Cassegrain.

Standard Tele-Extender

Use this Tele-Extender in conjunction with an eyepiece. Attaches to visual back of Meade or Celestron Schmidt-Cassegrain telescopes, and to 35mm camera with T-ring, sold separately.

#5125 **\$27.95** (1.89)

Variable Tele-Extender

Uses an adjustable extension tube, allowing magnification to be changed without switching eyepieces. Thumbscrews lock extension tube securely in place. Attaches to 35mm camera with T-ring, sold separately.

#5127 **\$39.95** (1.89)

Orion® Tele Compressor

Get four times the brightness and 1/2 the exposure time. Doubles your field of view for astrophotography. For Meade, Celestron 8", 10" SC.

#5141 **\$34.95** (1.89)



### Orion® SkyGlow® Enhanced Light Pollution Filters

Enhance your viewing of faint deep sky objects with the best broadband light pollution filter you can buy. Our SkyGlow absorbs frequencies emitted by city lights, allowing transmission of the rest of the visible spectrum, yielding dramatic results.



SkyGlow Broadband Filter-

For use in sight to moderately light polluted areas.

1.25" Broadband Filter-

fits 1.25" eyepieces #5660 **\$66.50** (1.89)

Schmidt-Cassegrain Broadband Filter-fits rear cell of Meade & Celestron SC scopes #5658 **\$99** (2.19)

52mm Broadband Filter-fits all camera T-rings #5668 **\$66.50** (1.89)

SkyGlow UltraBlock Filter-

For use in severely light polluted areas.

1.25" UltraBlock Filter-

fits 1.25" eyepieces #5654 **\$77.50** (1.89)

Schmidt-Cassegrain UltraBlock Filter-fits rear cell of Meade & Celestron SC scopes #5656 **\$119** (2.19)

### Orion® Color Filters for Eyepieces

Solar system observations are dramatically improved by Orion colored filters. For visual use, thread one into the barrel of any standard eyepiece. For planetary and lunar photography, Schmidt-Cassegrain owners can attach the filter to the eyepiece inside the telescope. Can also be threaded directly into a universal camera adapter.



Basic Set of 4 Filters .965"

Includes #80A Blue, #58 Green, #25 Red, #15 Yellow

#5510 Was \$36.95 Now **\$29.95** (1.89)

Basic Set of 4 Filters 1.25"

Includes #80A Blue, #58 Green, #25 Red, #15 Yellow

#5514 Was \$44.95 Now **\$39.95** (2.19)

Expansion Set of 4 Filters 1.25"

Includes #21 Orange, #47 Violet, #11 Yellow-Green, #82A Very Pale Blue

#5516 Was \$44.95 Now **\$39.95** (2.19)

Deluxe Set of 8 Filters 1.25"

Includes all the filters in our basic and expansion filter sets.

#5517 Was \$79 Now **\$74.95** (2.79)

Individual 1.25" Filters-

#80A Blue (#11040), #58 Green (#5540), #25 Red (#5536), #15 Yellow (#5532), #21 Orange (#5534), #47 Violet (#5538), #11 Light Yellow-Green (#5530), #82A Very Pale Blue (#5544)

**\$11.95 ea.** (1.99)

### Orion® Moon Filters

Cuts 87% of the light from the Moon. Reduces glare by uniformly reducing light transmitted over the entire spectrum.



For .965" Eyepieces #5664 **\$14.95** (1.89)

For 1.25" Eyepieces #5662 **\$14.95** (1.89)

### Variable Polarizing Filter Set

Adjustably reduces the light transmission of visual images, so you can see more detail. Also ideal for cutting glare from water, window glass during terrestrial observation.



For .965" Eyepieces #5558 **\$19.95** (1.89)

For 1.25" Eyepieces #5560 **\$24.95** (1.89)

### Porta Pac Rechargeable Batteries

5.0 Amp Hour Porta Pac Perfect for Meade LX6, LX5, and LX3, and Celestron Powerstar 8, and SPC-8 (with adapter). Also suitable for all drive correctors and motor drives. Battery is encased in high-impact polystyrene. Built-in handle. Wt. 5 lbs.



#2352 **\$69 ea.** (4.56)

12 Amp Hour Porta Pac Ideal for operating your telescope plus higher power-consuming accessories such as an Orion Dew Zapper Battery is encased in high-impact polystyrene. Carrying case of Cordura nylon with shoulder strap and handle. Wt. 10 lbs.



#2354 **\$99 ea.** (6.23)

### Orion® Motorized Slow Motion Control

Get the utmost in smooth tracking with this new motorized pan head. It attaches between any tripod and a binocular or spotting scope (maximum at 6 lbs.) with standard 1/4-20 threads. Two motors provide independent adjustment of vertical and horizontal motion. Auto Pan Mode allows continuous horizontal panning motion in a 30, 60 or 90 arc. Hand control features easy pushbutton directional control and variable speed adjustment. The maximum horizontal angle is  $\pm 90^\circ$ , the maximum vertical angle is  $\pm 15^\circ$ . Includes jack for 6V DC power supply. Uses 4 AA batteries (not included).



#5016 **\$189** (3.89)

### Orion® Star Diagonals

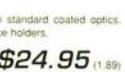
1.25" Star Diagonal Primarily for astronomical use, lets you view at a right angle. Multi-coated, for 1.25" eyepieces. Not compatible with most reflectors due to insufficient focussing range.



#8763 **\$39.95** (1.89)

.965" Star Diagonal

Same as 1.25" Star Diagonal, but with standard coated optics. Works with .965" eyepieces and eyepiece holders.



#8761 **\$24.95** (1.89)

Hybrid Star Diagonal

Adapts 1.25" eyepieces to .965" eyepiece holders of refractor and most compound reflectors (does not work with .965" Newtonian Reflectors).



#14008 **\$29.95** (1.89)

### Orion® 2x Rich Field Adapter

Get four times brighter image and twice the field of view. For Meade, Celestron 8", 10" Schmidt-Cassegrains.



#5128 **\$89** (2.29)

### Astrogoggles

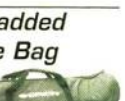
Allows eyes to adjust to night vision in the comfort of your home.



#5942 **\$19.95** (1.89)

### Orion® Deluxe Padded Field Tripod Tote Bag

Heavily padded Cordura bag with sturdy zipper holds tripod and wedge combinations for 8" and 10" Schmidt-Cassegrains. Large girth allows storage of wedge without changing polar alignment. Padded insert separates wedge from tripod during transportation. Internal pocket holds hardware.



#15096 **\$79.95** (4.28)

Economy Tote Bag-Similar to above without padding.

#15095 **\$34.95** (3.59)

### Popular Observer's Chairs

Make observing more comfortable and enjoyable with one of these great chairs.



Standard Model-

Has adjustable height center column and padded vinyl seat. Folds for easy storage.

#5935 **\$39.95** (3.69)

Deluxe Model-

Is much heavier-duty, built for professional musicians. Extra thick padding, wide footprint. Adjustable, disassembles for storage.



#5934 **\$88** (5.65)

### Deluxe Metal-Clad Accessory Cases

Keep your accessories, camera, safe and clean. Diced foam inserts can be tailored to your needs. Sturdy handle, two latches with key.



Regular Case-16"x12"x5-1/2"

#5920 **\$49.95** (5.09)

Large Case-19-1/2"x12"x6-1/2"

#5921 **\$64.95** (5.92)

### Orion® Dual Balance System

Finally, a simple balance system that really works! Unlike ordinary counterweights, our system allows instant adjustment in both directions. Easily balances your scope to offset both piggyback loads or rear-cell cameras, 2" diagonals, and other accessories. Rigid precision machined dovetail bar mounted to telescope in existing accessory holes.



For Meade 8" 2080 #5150 **\$74.95** (3.46)

For Celestron 8" C-8 #5149 **\$79.95** (3.46)

For Meade 10" 2120 #5152 **\$84.95** (3.46)

### Orion® Dew Zapper

Orion's Dew Zapper is a sure fire cure for dew problems on your 8" or 10" Celestron or Meade Schmidt-Cassegrain telescope. Dew Zapper gently replaces lost heat by bringing the corrector plate temperature slightly above air temperature.



8" Dew Zappers-fits all Meade and Celestron 8" Schmidt-Cassegrains

DC Model #3503 Reg. \$39.95 **\$34.95** (1.79)

AC Model #3504 Reg. \$39.95 **\$34.95** (1.79)

10" Dew Zappers-fits all Meade 10" Schmidt-Cassegrains

DC Model #3506 Reg. \$44.95 **\$39.95** (1.79)

DC Model #3508 Reg. \$44.95 **\$39.95** (1.79)

Dew Remover Gun

Moisture that interferes with viewing dissipates quickly with this 12V DC. 156 watt warm air gun. Has a 1-1/2 cord.



#5601 **\$17.95** (2.09)

### Starlite Red LED Flashlight

The Starlite is the only adjustable brightness night-vision red flashlight. Lifetime solid-state LED can't burn out. Extra efficient electronic circuit for long battery life. Uses one 9-volt battery (not included).



#5714 **\$24.95** (1.89)

### Astronomer's Flashlight

Indispensable and indestructible. Has special night-vision red filter and a diffusion lens for even illumination. An essential addition to your astronomy accessories. Requires 2 D-cell batteries (not included).



#5701 **\$8.95** (1.89)

### NiteWriter Pen

Incredible pen with built-in red light! With extra refill batteries.



#5709 **\$8.95** (1.89)

### Large Deluxe Eyepiece Case

A larger version of our popular case. Available in universal diced foam version you tailor yourself, or die-cut model perfect for 2" star diagonal and both 2" and 1.25" eyepieces and accessories. O.D. 9-1/2"x13-1/2"x5-1/8"



Large Deluxe Case with Pre-Cut Foam

#5916 **\$29.95** (2.69)

Large Deluxe Case with Diced Foam

#5914 **\$27.95** (2.69)

### Deluxe Eyepiece Case

Organize and protect your valuable eyepieces and other accessories. This durable case with double hinges holds up to 10 eyepieces plus secure fit. Die cut foam insert for snug secure fit. O.D. 9-1/2"x12-1/2"x3-1/8"



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# AMATEURS WATCH SOVIETS BUILD MIR

In early December 1989 Canadian amateur astronomers observed a critical step in the construction of the Soviet *Mir* space station. The mission was the docking of a 46-foot long module called *Kvant II* with the existing *Mir*, doubling the size of the station. But the *Kvant* rendezvous was not without its problems, problems that were observed by Canadian amateurs.

The *Kvant II* module was launched on November 26, 1989. The plan was a December 2 rendezvous with *Mir*, then manned by two cosmonauts. A successful docking was critical to the Soviet's expansion of the *Mir* complex. The *Kvant II*, unlike its predecessor, *Kvant I*, is not just an experiment and telescope unit, but also a living quarters module with an EVA hatch, robot arm, and additional solar panels. *Kvant II* is the first of three house-sized modules scheduled to be added to *Mir* over the next few years.

On December 2 Radio Moscow announced that the unmanned *Kvant* had failed to make the final orbital corrections required for the rendezvous. Canadian amateur satellite tracker Ted Molczan of Toronto, Ontario, who monitors Radio Moscow for just such news, alerted amateur astronomers across Canada. Molczan calculated when *Mir* and *Kvant* would be visible from Canada. Amateur astronomers in Alberta, Manitoba, and southern Ontario were able to watch the two craft pass overhead on several orbits over the next few nights. Both appeared as star-like objects with a magnitude of -1.

On December 2 *Kvant* and *Mir* were about 3 minutes apart. Timings of the passages over the next few nights helped Molczan determine the actual orbits of the two craft. *Kvant* was indeed slowly closing in on *Mir*. Observations like these help space program enthusiasts follow both Soviet and U.S. missions first hand, supplementing the often sketchy information from official news sources.

By December 6 the Soviets had overcome the initial problem and completed the docking. The next step in the expansion of *Mir* is the addition of another *Kvant* module this month. Amateur satellite trackers around the world

will be watching with interest.

Amateurs who wish to participate in tracking satellites like *Mir* are invited to call Ted Molczan at (416) 928-3046 for more information. Molczan can also be reached via modem by leaving a message on the Canadian Space Society Bulletin Board at (416) 458-5907 (2400 baud, 24 hours, no fee.)

## TELESCOPE MAKER ROBERT E. COX DIES

World renown telescope maker and popularizer Robert E. Cox passed away in O'Fallon, Missouri, on December 16, 1989. Cox had served as Associate Editor of *Telescope Making* magazine since 1978 and was for years an enthusiastic supporter of amateur astronomy meetings around the country.

Cox was born in Cleveland in 1917 and educated in local schools in Brooklyn, New York. During the 1930s he developed a strong interest in telescopes and made a 10-inch reflector. A decade later Mr. Cox joined the Perkin-Elmer Corporation as an optical engineer and served briefly during World War II as a weather observer in the Army Air Force.

Subsequently Mr. Cox settled in St. Louis where he worked for McDonnell-Douglas and often lectured at the St. Louis Science Center. Through experimentation and self-taught theoretical knowledge, Mr. Cox designed many telescopes and sophisticated optical systems and worked on the *Gemini* space program. He wrote the "Gleanings for



ATMs" column for *Sky & Telescope* before joining the staff of *Telescope Making*. Mr. Cox is survived by his wife and two children.

## SMITHSONIAN OFFERS ASTRONOMY SEMINARS

The Smithsonian Institution has initiated a major program to bring science education to the public by holding periodic seminars on selected scientific topics. This spring the Smithsonian National Associates Program offers ten seminars on a variety of subjects, including a pair of five-day seminars on the frontiers of astronomy to be held in May at the Smithsonian's Whipple Observatory in Tucson, Arizona.

"The astronomy seminars are designed for amateur astronomers," said Amy Warner of the Smithsonian Institution. "The seminars will feature a wide range of lectures on optical astronomy, mirror technology, quasar research, infrared radiation, and modern astronomical thinking on the Big Bang."

Faculty for the seminar will include astronomers from the Whipple Observatory and the University of Arizona. Talks will include a session on the *Voyager 2* Neptune encounter by Bradford Smith, head of the *Voyager* imaging team.

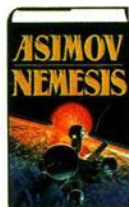
The seminars, titled "The New Astronomies," will be held between May 13 and 18 and also May 20 and 25, 1990, at the Grace Flandrau Planetarium on the University of Arizona campus. An introductory talk by Daniel Brocious will be followed by lectures on quasars by Craig Foltz and an exploration of gamma-ray astronomy by Trevor Weekes. A field trip to Mt. Hopkins to see the Multiple Mirror Telescope, the world's third largest optical telescope, is scheduled for the second day.

The following day features talks by Frederic Chaffee on the MMT and a discussion by Roger Angel of his technique of spin-cast mirror making for large reflecting telescopes. The final two days include a trip to Kitt Peak, talks on automated telescopes by John McGraw and infrared astronomy by Marcia Rieke. The finale is a star party at Sabino Canyon outside of Tucson.

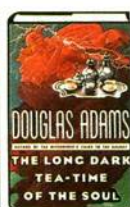
Other seminars in the series include America's Future in Space, Exploring the Sea, and Animal Communication. For more information on any of the Smithsonian programs, contact the Associates Travel Program, 1100 Jefferson Drive S.W., Washington, DC 20560. □



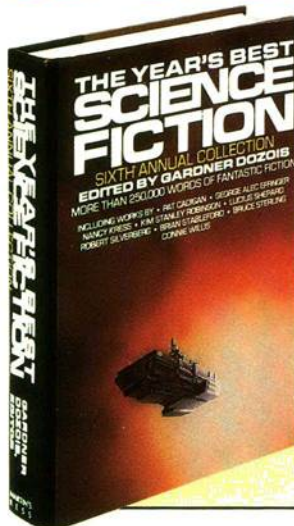
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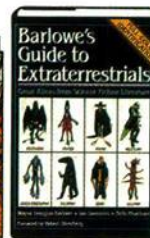
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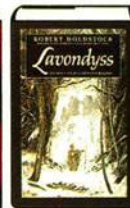
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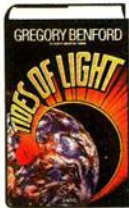
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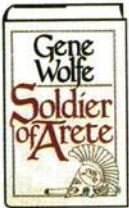
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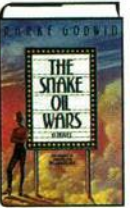
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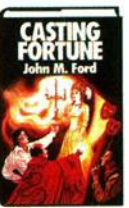
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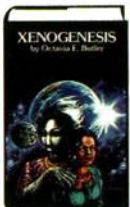
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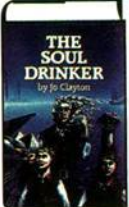
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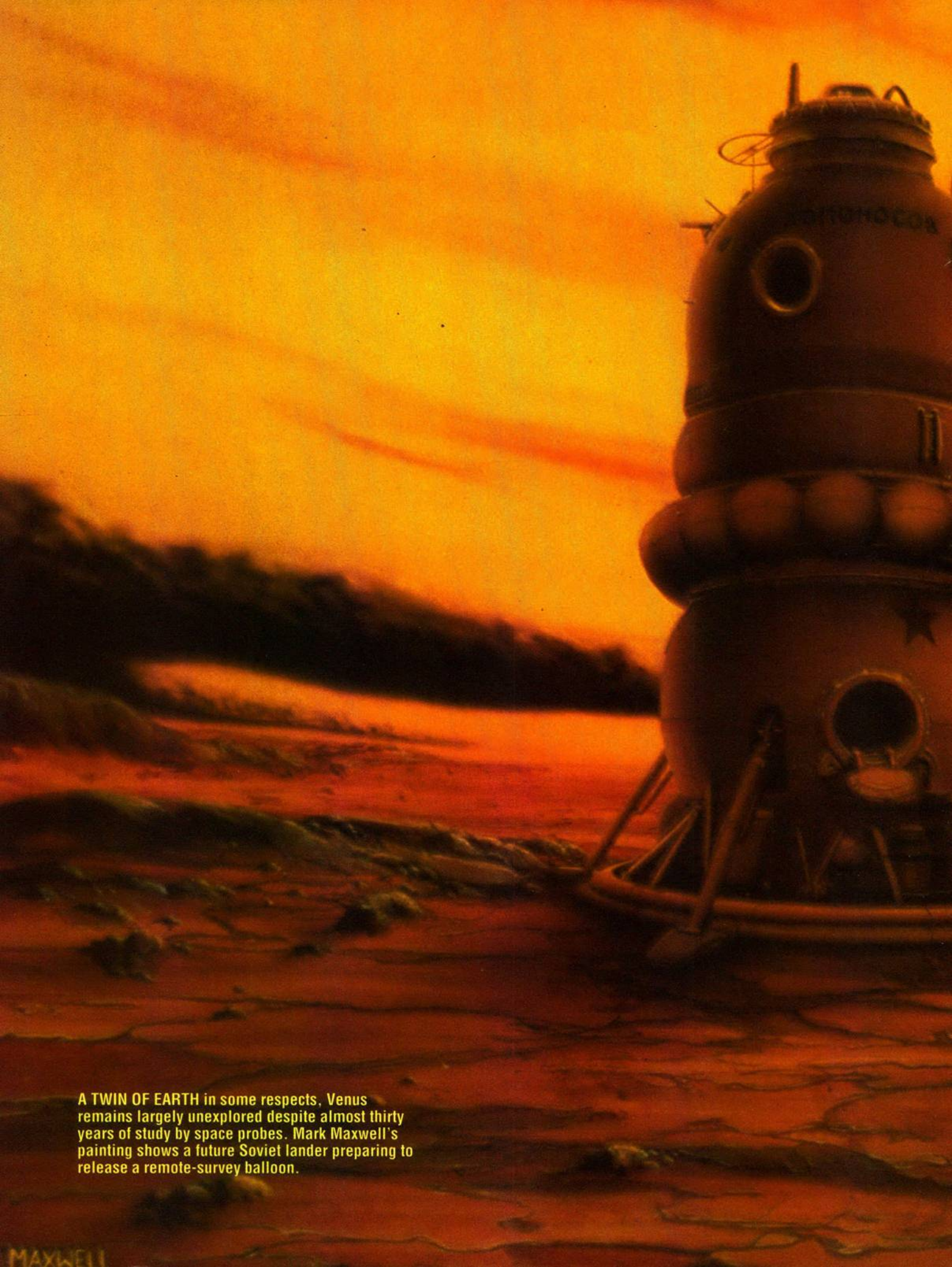
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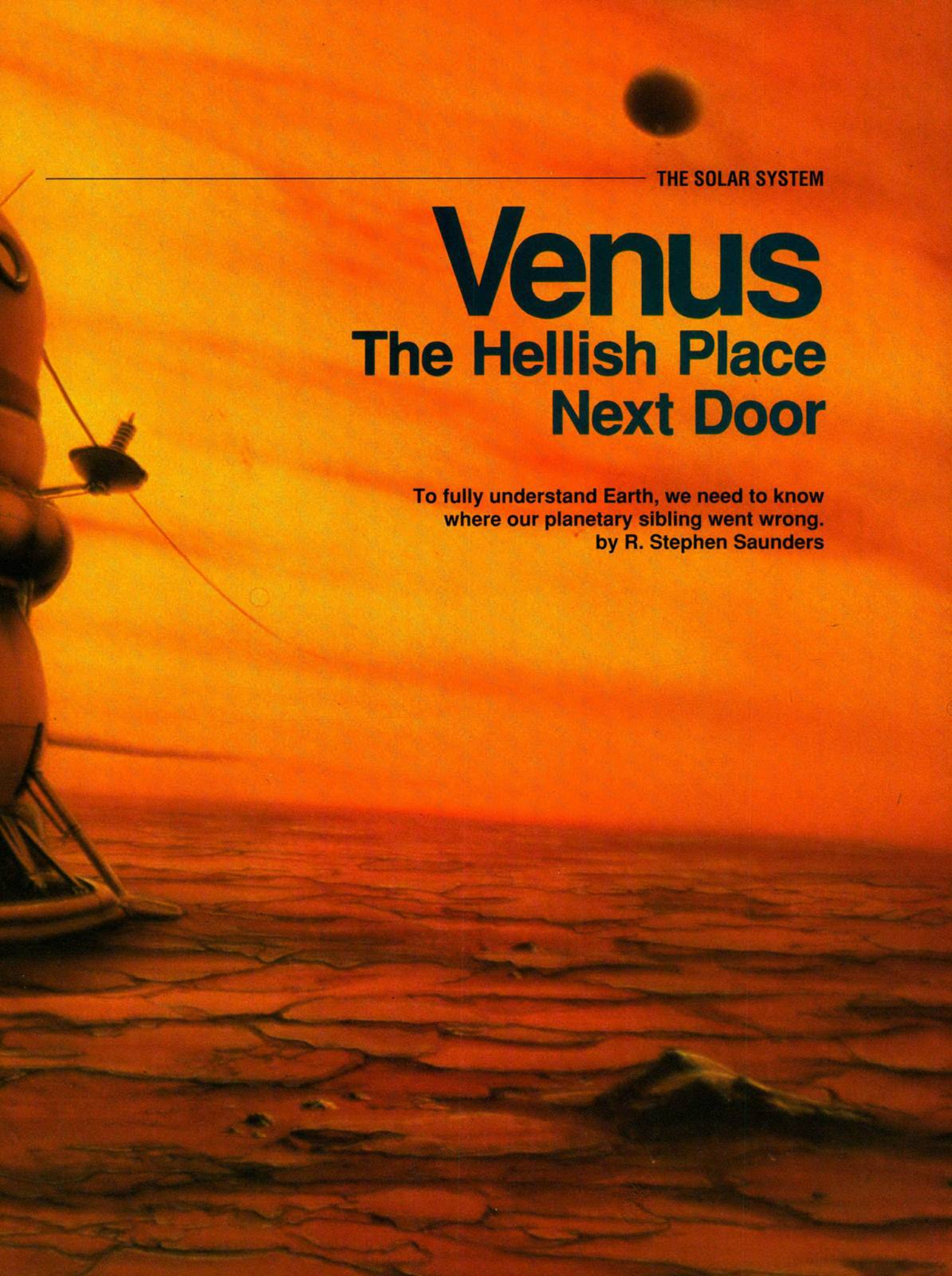
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A TWIN OF EARTH in some respects, Venus remains largely unexplored despite almost thirty years of study by space probes. Mark Maxwell's painting shows a future Soviet lander preparing to release a remote-survey balloon.





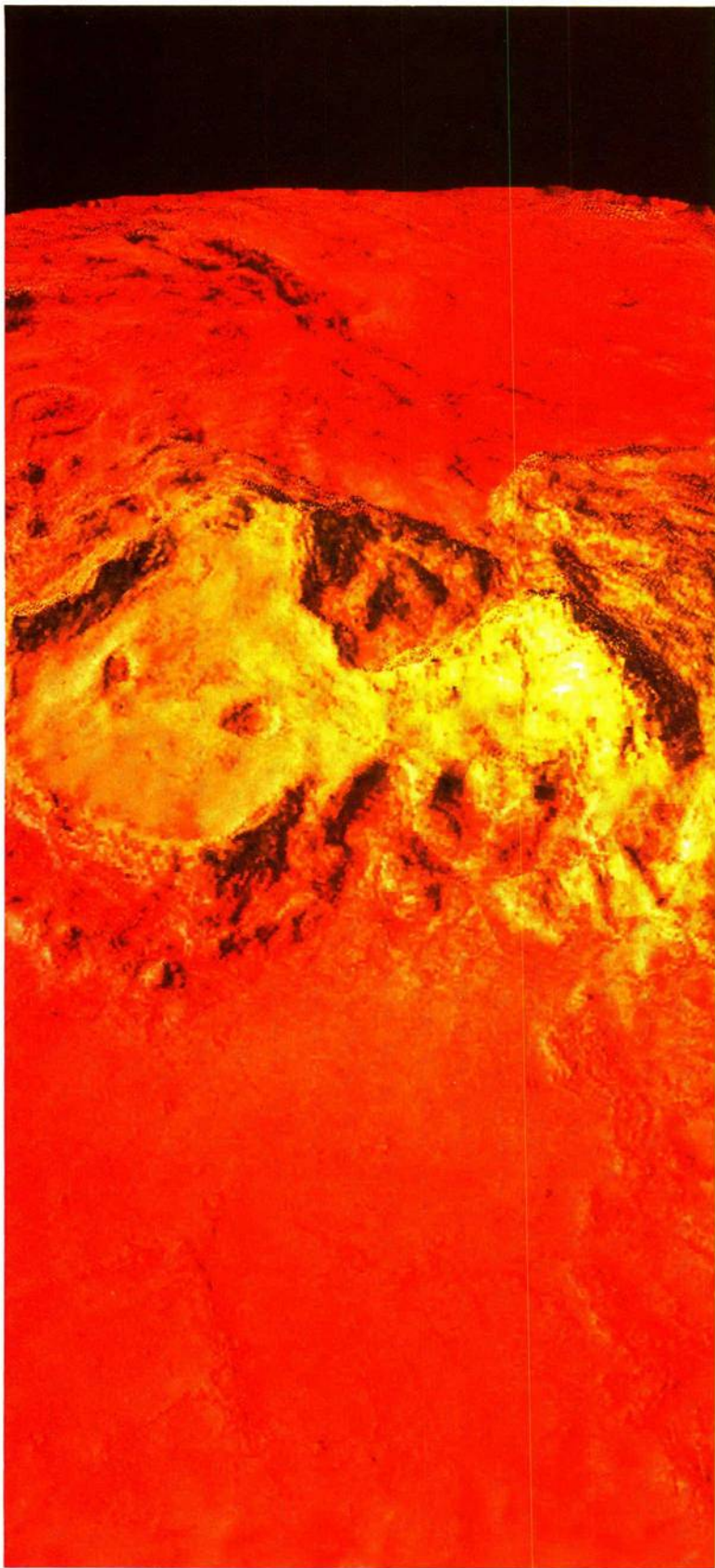
THE SOLAR SYSTEM

# Venus

## The Hellish Place Next Door

To fully understand Earth, we need to know  
where our planetary sibling went wrong.  
by R. Stephen Saunders





**AS LARGE AS AUSTRALIA**, the "continent" Ishtar Terra contains Venus' highest mountain, Maxwell Montes (right center), which is higher than Mt. Everest. The two "dimples" in Lakshmi Planum (left) are volcanic calderas.

**V**enus is important to everyone who lives on Earth. Of all the worlds in the solar system, no other comes as close to being a twin of our own planet in size, mass, and composition. Moreover, both Earth and Venus shared the same early experiences. Yet at some forgotten point their evolutionary paths began to diverge and they turned out hellishly different. How this happened is one of the solar system's greatest unanswered questions. It is also a question with more than ordinary urgency: As we Earthlings continue to alter our environment, the answers we seek at Venus may well have a critical relevance for our own planet.

Mankind's attempts to explore this sibling world have long been frustrated. Venus' surface is totally hidden from view by dense clouds of sulphuric acid. The only way to peer beneath the clouds and take an inventory of the planet is by radar. The first steps have already been taken. A decade ago *Pioneer Venus* provided the first nearly global radar maps; six years ago the Soviet *Venera* probes detailed the north polar region. Yet because we still don't know even some of the most basic facts about the surface of Venus, the exploration is continuing.

The United States' *Magellan* spacecraft is speeding toward a rendezvous with Venus on August 10. Right now, its team of planetary scientists is busily gearing up to analyze the flood of data that will come streaming back from the craft once it goes into orbit around Venus. *Magellan's* powerful radar will spend at least eight months mapping this sister world of ours as it has never been mapped before. The end result of a successful mission will be the first reasonably complete survey of Venus.

#### Two Peas From a Solar Pod?

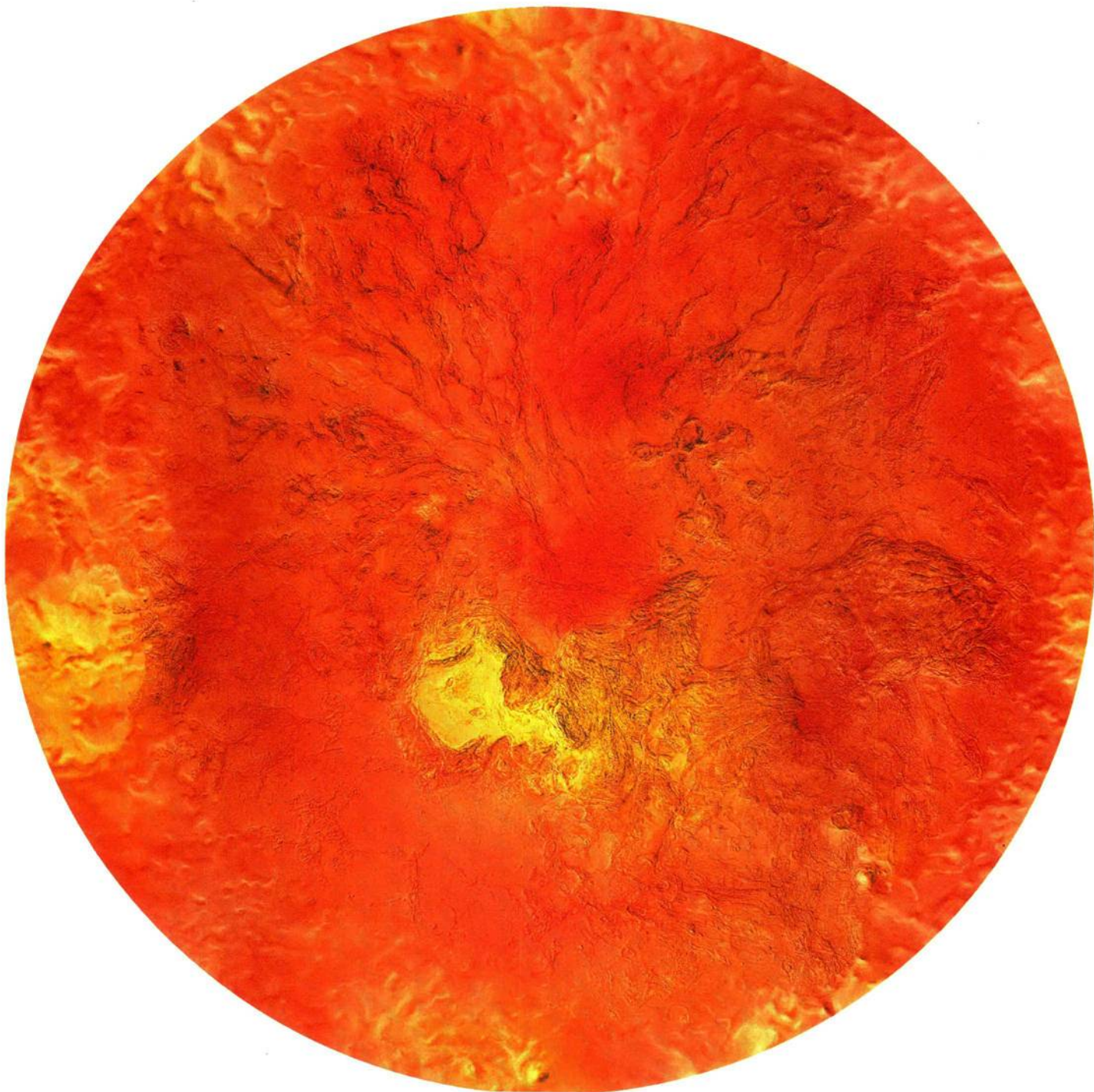
When the solar system condensed out of the warm nebula of dusty gas surrounding the early Sun 4.6 billion years ago, Earth and Venus formed in very similar regions. They are nearly identical in bulk composition and were subjected to similar external influences. For their first 800 million years, a period that planetary scientists call the early intense bombardment, both Earth and Venus were repeatedly hammered by a heavy rain of asteroidal debris as the last pieces that formed the planets were swept up.

In this early stage, the surfaces of Earth and Venus probably looked about the same: a thin new crust, broken through in many places by fresh impact scars, overlying an ocean of molten rock. (See "Piecing Together Earth's Early History," June 1989.) Then, as both planets' crusts cooled further and thickened, tectonic movements began to push up landforms and mark their surfaces in a lasting way.

As befits siblings, many of the geological processes taking place on Earth also occur on Venus. Thanks to space probes and radar, we already have convincing evidence of Venusian impact craters, volcanic features, and various kinds of tectonic deformation. Even at smaller scales the parallels continue. Four Soviet *Venera* landers have provided basic analyses of the composition of Venus' surface rocks. These indicate that, like Earth, Venus is differentiated: It melted throughout so that its heavier elements sank to form a core, while lighter elements such as silicates (granites) floated up to form a mantle and crust.

If the parallels with Earth hold true, the upper layers of Venus should contain a higher concentration





of radioactive isotopes than do the deeper parts. As these isotopes decay they release heat that, on Earth, provides energy to drive plate tectonics, the great geological engine that grinds continent against continent and makes mountains and ocean trenches. Most of Earth's interior heat bleeds away in places where new volcanic crust is forming along the spreading mid-ocean ridges. But Venus lacks ocean basins, spreading ridges, and continents. How does it get rid of its heat? And what changes does the heat loss produce on the face of the planet?

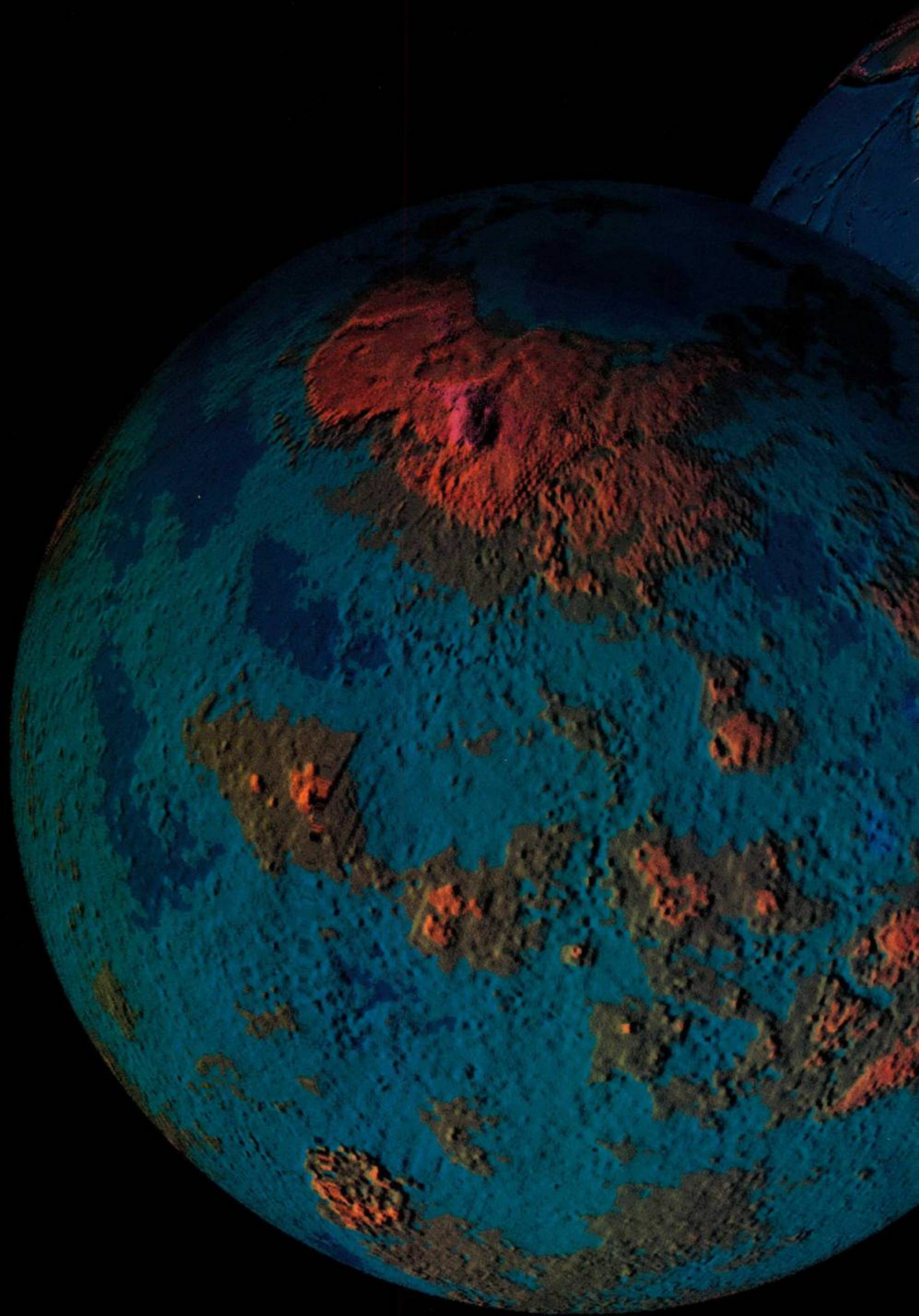
Soviet *Venera* radar images show that at least a quarter of Venus' crust has been deformed by geological forces that fractured and uplifted the terrain. It ap-

**SOVIET AND AMERICAN DATA COMBINE** in this view centered on Venus' north pole and extending down to 20° north latitude; Ishtar lies just below center. Scientists think the ropelike ridges at upper left are tectonic in origin.

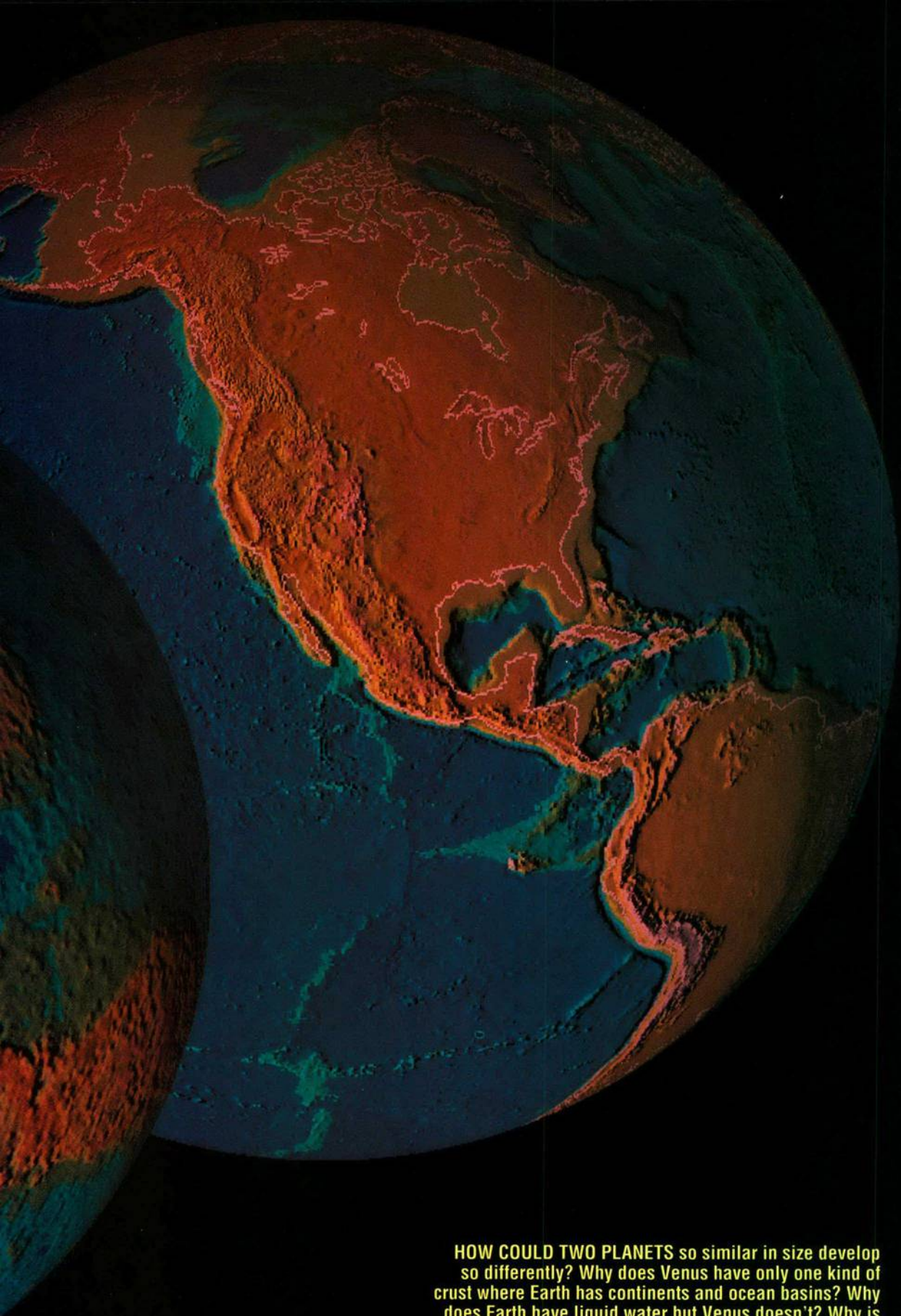
pears, therefore, as if heat is driving much the same kind of geological machine on Venus as on Earth.

We should be careful, however, not to assume that Venus "works" the same way Earth does. It's important to remember that landscapes on Earth, unlike those on Venus, are produced in the presence of a powerful erosive force — running water. This means that we almost never see terrestrial landforms in their pristine



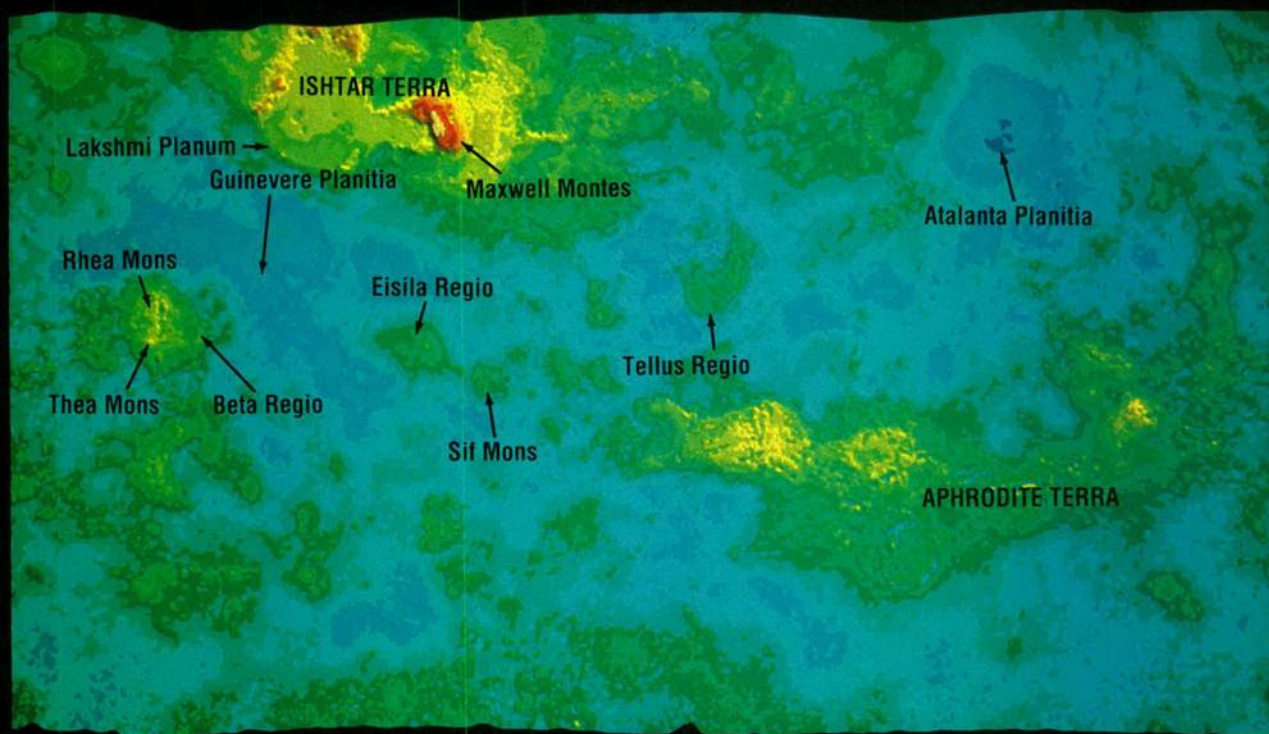






**HOW COULD TWO PLANETS** so similar in size develop so differently? Why does Venus have only one kind of crust where Earth has continents and ocean basins? Why does Earth have liquid water but Venus doesn't? Why is Venus' atmosphere 90 times heavier than Earth's? To understand our planet better, scientists need to know what these differences mean.





state. A mountain range, for instance, is uplifted over millions of years, but its shape is produced by the interplay between the forces that create the mountain and the running water that seeks to destroy it. Depending on the relative rates of these processes, a mountain range may rapidly become lofty or it may erode nearly as fast as it rises.

Because of Venus' lack of running water, landscapes there may well look significantly different from those geologists are used to. Despite a dense atmosphere, Venusian winds are too slow to erode effectively. But some erosion does occur. Among the fresh, sharp-rimmed impact craters, only one in four has a radar-bright apron of ejecta around it; some process has smoothed the other three. The problem is scientists do not know how fast the process works, and in any case it may be a kind of chemical erosion rather than the physical erosion that wind produces.

Earth and Venus also have chemical differences. The two contain about the same amount of carbon, outgassed by volcanos in the form of carbon dioxide. The difference is that on Venus virtually all the carbon dioxide remains in the atmosphere, which is 97 percent carbon dioxide. Earth took a very different route. Almost all of its carbon dioxide has been removed from the atmosphere by the oceans, a process that continues today.

Microscopic ocean organisms use carbon dioxide dissolved in seawater to make calcium carbonate body parts and shells. When the creatures die, their carbonate remains sink to the ocean bottom. There they combine with carbonates precipitated directly from the water to lay down thick beds of sediment that in time

**THE GEOGRAPHY OF AN ALIEN WORLD**, mapped by Pioneer Venus, shows only two continental masses, Ishtar and Aphrodite. (This Mercator projection exaggerates the size of Ishtar.) The smaller rises are probably shield volcanos.

become limestones, dolomites, and marbles. In addition, a small fraction of Earth's carbon lies in deposits of petroleum, natural gas, and coal.

Although Venus shares many bulk similarities with Earth, conditions at their surfaces are utterly different. The atmosphere presses down on the Venusian surface 90 times harder than on Earth, equalling the pressure found a kilometer deep in the ocean. Night and day the temperature is about 480° Celsius, hot enough that lead would run like water and hotter than high noon on Mercury at perihelion.

It may turn out that Venus and Earth evolved in such different directions solely because of slight compositional variations. The fact that Venus lies nearly 30 percent closer to the Sun may have played a role also. In addition, life, once it emerged, was clearly a major factor. It modified Earth by removing carbon dioxide and releasing oxygen. Although calcium carbonate would be precipitated without life, for much of geologic time living organisms have been the chief agents removing carbon dioxide from Earth's atmosphere.

In the end, though, a disturbing thought lies behind the questions we pose about Venus: Did Venus "go wrong" because of slight differences from Earth, or were the two destined to follow different paths right from the beginning? How delicate is the balance? Do these apparently irreversible processes have a hair-



trigger? To put it more directly, could something like this still happen to us? Today, no one pretends to have answers to these questions, but as the details of Venus come back to us from *Magellan* it might be wise to keep such larger issues in mind.

### Reading a Hidden Landscape

When *Magellan* begins mapping Venus late this summer, it will not be surveying *terra incognita*. Much of the Venusian map has already been crudely sketched by radar from Earth and orbiting spacecraft. Arriving at the planet in late 1978, *Pioneer Venus* used its radar altimeter to map the Venusian terrain at coarse resolution, about 50 kilometers. Out of this data came the first nearly global Venus maps (see this page and opposite).

The Soviet *Venera 15* and *Venera 16* missions, active in 1983 and 1984, used radar to make more detailed images of the northern quarter of the planet at a resolution of 1 to 2 kilometers (see page 21). More recently scientists using the Arecibo and Goldstone radio telescopes have made the best-yet radar images of Venus from Earth. These observations produced views of limited regions of the planet at resolutions of 1 to 2 kilometers (see pages 26 and 27). *Magellan's* best views will have resolutions of slightly under a kilometer, and most of the planet will be mapped.

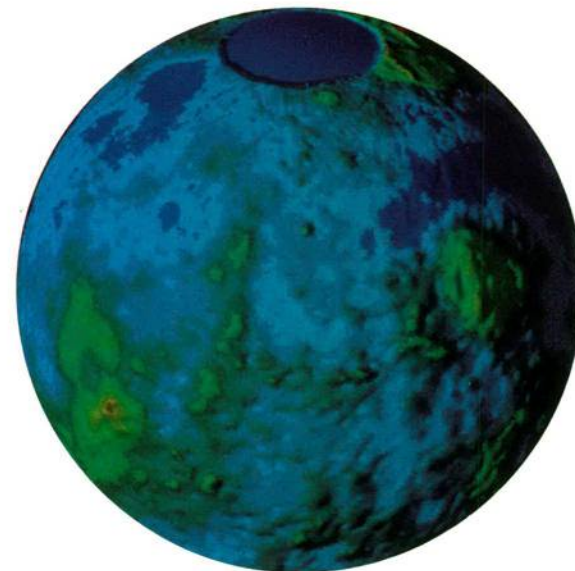
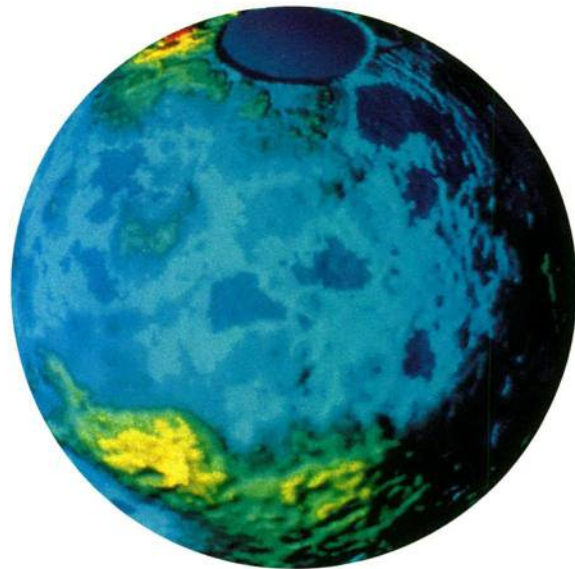
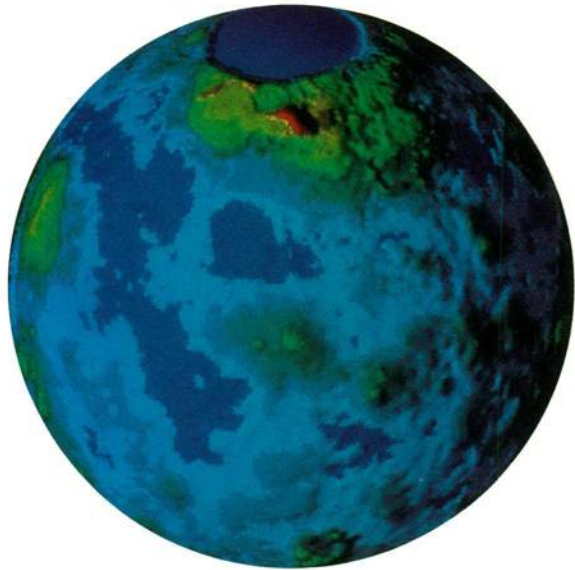
The *Pioneer Venus* results pointed out an interesting difference between Venus and Earth. Most of Venus lies at roughly one elevation with only small areas differing significantly from the planet's mean radius of 6,052 kilometers. Earth, on the other hand, has two distinct topographic levels: the ocean basins, covering 70 percent of the planet, and the continental plains, which lie about three kilometers higher.

This single fact has wide-ranging implications. A one-level topography appears to indicate that only one kind of crust evolved on Venus, unlike Earth's two. The major Venusian physiographic provinces are the lowlands (27 percent), rolling uplands (65 percent), and highlands (8 percent). On Earth, the 70 percent of the surface represented by ocean basins is underlain by volcanic rocks. The continents are mostly sedimentary or plutonic rocks; that is, molten rock that crystallized deep in the crust.

The existing data for Venus indicate that most of its surface is bedrock covered with blocky rocks and loose debris. The rolling plains appear to be volcanic in origin. Venus, in short, looks like a planet-wide ocean bottom — minus the ocean.

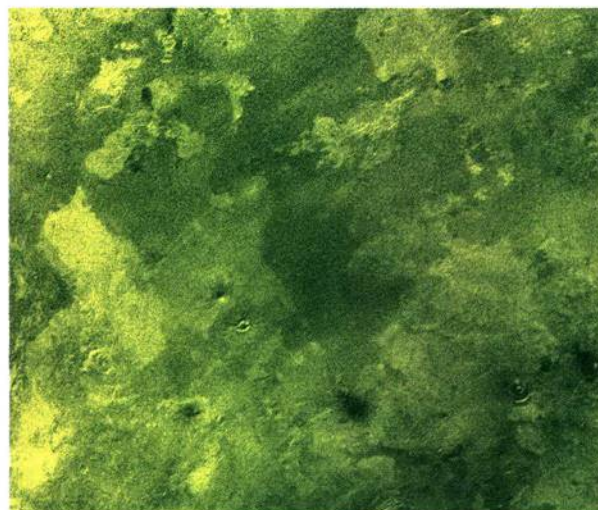
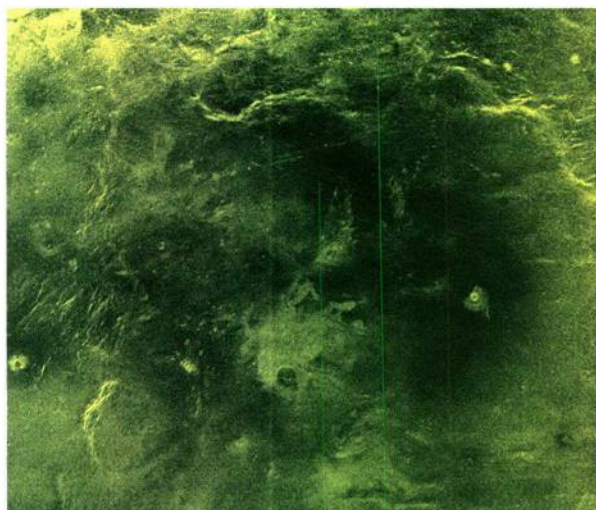
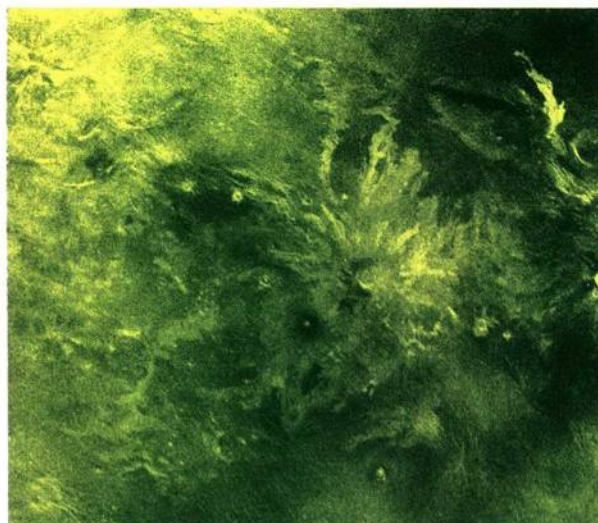
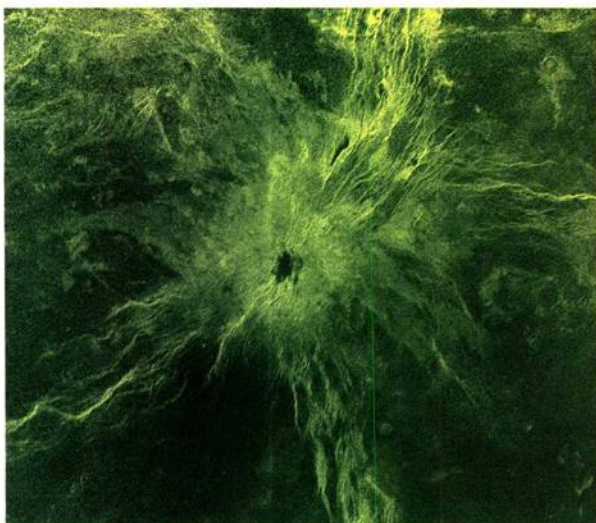
Scientists would like to know if the highlands on Venus resemble terrestrial continents in composition. The scanty data are hardly conclusive, but there is no overwhelming evidence for the thick beds of water-laid sedimentary rocks that cover much of Earth's continents. However, at the *Venera 8* and *Venera 13* landing sites the spacecraft did find differentiated rocks that could be plutonic (continental) in origin.

Venus has many tectonic features, some of which resemble those on Earth. Superimposed on the northern plains in many places are complex narrow belts, 10 to 25 kilometers across and consisting of low ridges and



**THREE HEMISPHERES** spaced 120° apart display Venus as a globe. The top view has Ishtar in the center, the middle view shows the equatorial continent Aphrodite, and the bottom view is centered between Aphrodite and Beta Regio.





**EARTH-BASED RADAR HAS EXPLORED** small regions of Venus. At top is Thea Mons (left) and Sif Mons. Note the streams of radar-bright material, which are probably lava flows. The lower pair is in Guinevere Planitia.

grooves. These low-relief features, and the mountains surrounding Lakshmi Planum, resemble folded mountains on Earth such as the Appalachians.

The plains of the north are generally smooth but contain scattered fields of rocky domes 15 to 20 kilometers in diameter, which are thought to be volcanic in origin. Several areas within the northern plains also contain circular domes 50 to 300 kilometers across. These are less than a kilometer high, a fact that suggests they are shield volcanoes, low structures built up from very thin, runny lavas that oozed out quietly and spread great distances before they hardened.

The question of whether Venus has active volcanos is tantalizing. When *Pioneer Venus* arrived a dozen years ago it measured the sulphur dioxide in the atmosphere. The amount has steadily declined ever since and one straightforward explanation is that an eruption ended shortly before *Pioneer* arrived. It's exciting to imagine active volcanos on Venus, but the chemical sources and natural cycles for Venusian sulphur dioxide are too poorly understood to say for sure.

Another argument in favor of volcanism are the observations by *Pioneer* of a kind of radio signal that typically comes from lightning. Terrestrial volcanic

eruptions often generate lightning. However, on Earth lightning is much more commonly associated with storms, especially in mountainous regions. Although no one has suggested that such storms occur on Venus, the planet does have mountainous highlands, so who knows?

Venus also shows features that have no counterpart elsewhere. Tesserae, from the Greek word for tiles, are roughly orthogonal systems of ridges and grooves a few hundred meters high and spaced about 5 to 20 kilometers apart that are found in elevated regions. The best example occurs at the east end of Ishtar Terra, but it appears likely that tesserae are widespread on Venus, occurring in patches more or less equal in area. Alpha Regio, a major feature long observed by Earth-based radar, may also be a region of tesserae, but because it lies outside the region mapped by *Venera*, scientists will need *Magellan's* detailed views to decide.

Another unique class of Venusian landform is the corona, from the Latin word for crown. Coronae are quasi-circular rings of concentric ridges with relief measuring less than a kilometer. The diameter of their outer rings can range from 150 to 600 kilometers, and



they probably result from a combination of volcanic and tectonic processes. (More than anything else, coronae resemble giant collapsed soufflés!) Smaller circular features also appear to be volcano-tectonic in origin. These are called paterae and are 50 to 200 kilometers in diameter.

How old is the surface of Venus? On Earth the oldest parts of the ocean floors are about 250 million years old, while on the continents rocks as old as 4 billion years have been found. For Venus, from which datable rock samples are lacking, planetary scientists fall back on counting craters, using an assumed infall rate. The mapping done so far shows several of the northern plains ridge belts are marked by impact craters. The population of craters suggests the plains are at least 200 million years old and perhaps as much as a billion. Unfortunately, the data have so many unknowns that until better mapping reveals the relative numbers of craters at all scales, the age of the surface will remain largely guesswork.

The dominant geological mechanism on Earth is plate tectonics. The outer part of Earth is made up of a number of rigid plates that move around like huge, rocky rafts on convection currents in the mantle. Along mid-ocean ridges, new crust forms where the plates spread apart; old oceanic crust returns to the mantle in zones of subduction, which usually lie at the edges of continents. Subduction zones, where oceanic plates dive under the continents, are the sites of the strongest earthquakes, the most active volcanos, the deepest trenches, and the highest mountains.

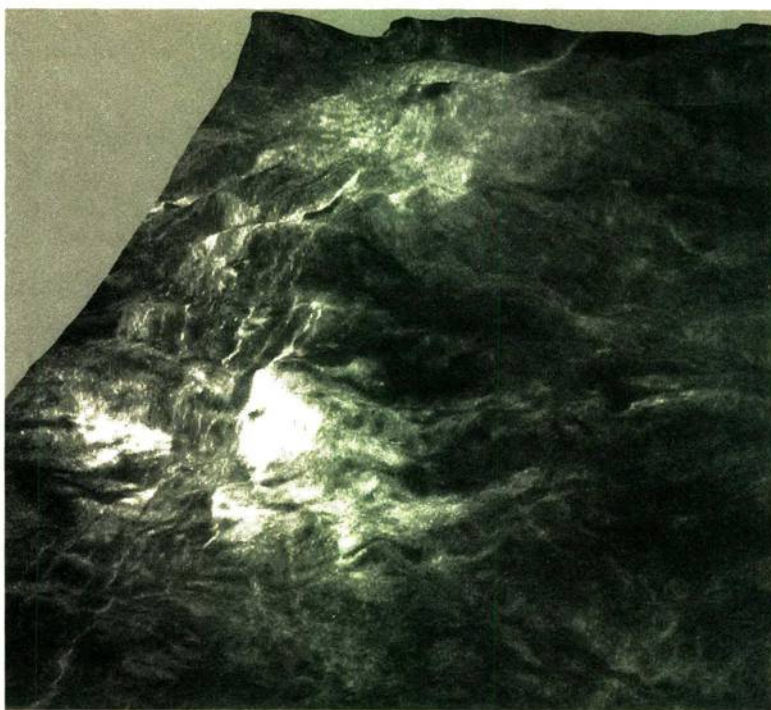
Scientists have generally assumed that Venus should exhibit many of these features since it is so similar to Earth in size and mass. But although a few regions show features that resemble plate tectonic elements on Earth, no global system like Earth's has yet been identified. Moreover, scientists have come to believe this lack is not simply a result of mapping at scales too coarse to reveal it. Instead, the lack of global plate tectonics appears to be a real and therefore significant difference between the two planets.

Venus may yet turn out to be much less active at the surface than Earth — or more active. The answer must await the high-resolution radar images from *Magellan*. However, even the low-resolution data we have point to notable differences in the relation between gravity and topography on the two planets.

On Earth there are areas where the gravity is slightly less or slightly more than the average. Regions of lesser gravity are underlain by lower density rocks; the opposite occurs in higher gravity regions. Basalt rock, for example, is denser than granite and granitic continents therefore "float" on basalt. Temperature differences can also produce gravity anomalies because hotter rock is less dense.

Venus shows a strong correlation between topography and gravity. Geophysical modeling demonstrates that most of the gravity anomalies associated with the Venusian highlands come from deep in the mantle. The rocks in the interior act like a liquid, and on scales of thousands or millions of years they can literally flow. This strongly hints that most of the highland regions of Venus are supported by slowly flowing, hot rock deep in the mantle. Geophysicists call such flows mantle plumes or "hot spots."

The equatorial highlands of Aphrodite Terra show



**LOOKING SOUTH OVER BETA REGIO**, this view shows radar brightness, which indicates surface roughness. Thea Mons is the more distant of the two volcanos and sits atop a rift zone that has disrupted Rhea Mons, the closer peak.

an interesting trend. It appears that the highlands in the west end of Aphrodite are supported at rather shallow levels, less than 100 kilometers, but toward the east the support comes from progressively deeper regions. Around the planet at Beta Regio, the support may be as deep as 300 kilometers. This trend is so regular as to suggest that the western parts of Aphrodite are oldest and the highlands get progressively younger to the east. Is this a series of hot spots migrating east, or is the crust moving westward over a fixed hot spot? If it exists, this hot spot would be as massive relative to Venus as the Tharsis Bulge and its giant volcanos are to Mars. In any case, it looks as if differences between the tectonic styles of Earth and Venus are far more than crust deep.

#### Did Venus Have Oceans?

Venus' surface is like an ocean bottom; could it in fact be an ocean bottom? Might waves have once rolled across the planet to crash on the shores of Ish-tar? Did streams scour the flanks of Beta Regio? At present the surface of Venus is far too hot for liquid water to exist, but could conditions have been different in the past?

This simple question, unfortunately, has no equally simple answer. The question of a Venusian ocean can be explored several ways, but since the surface is exceedingly dry today, all the evidence is circumstantial. The most scientists can do is draw inferences about early conditions from models of planetary accretion, from direct measurement of the isotopic composition of the atmosphere, from surface composition, and from analysing radar images.

The best planet-formation model scientists have





**THE "GROUND TRUTH" ON VENUS** is shown in this photo taken by the Soviet Venera 14 probe, which landed on the plains southeast of Beta Regio. Little soil is visible and the slablike rocks are basalt, a volcanic material.

predicts a dry Venus. It proposes that the material from which the planets condensed surrounded the early Sun as a flat, gaseous nebula, hot and dense in the center and cooler and less dense toward the margin. Elements and compounds formed as solids or gases depending on the temperatures and pressures around them.

Only high-melting-point elements like iron could condense close to the proto-Sun, so Mercury inherited a large fraction of iron. By itself water could become liquid or solid only at greater distances from the Sun, near the current orbit of Mars. But water combined with silicates in water-bearing minerals could form at about where Earth is. These water-bearing minerals became the source of our planet's water. According to the model, however, temperatures were still too high at Venus for these minerals to form. Thus, says the model, Venus is and always was dry.

But planetary exploration has shown that the planets probably did not condense in a simple way and in one place. Initially, matter condensed into metallic, rocky, or icy planetesimals depending on where they were in the solar nebula. These planetesimals in turn collided and formed larger bodies, but as these objects formed, gravitational interactions could have mixed and propelled them out of the regions where they formed. We see this process happening today in comets that wander in from the outer parts of the solar system, and by the fact that in meteorite collections scientists have samples of most kinds of asteroids.

Therefore, it may not matter how dry Earth and Venus were when they formed. Comets or water-rich meteorites could have dumped significant amounts of water on both at any stage in their development.

Indirect evidence for past water on Venus comes from a *Pioneer* Venus observation of the deuterium-to-hydrogen ratio in Venus' atmosphere. Deuterium is hydrogen with an extra neutron in its nucleus, which makes it nearly twice as heavy as ordinary hydrogen. Water has about 10,000 hydrogen atoms to every one of deuterium. As sunlight breaks water up into its hydrogen and oxygen components at the top of the atmosphere, the hydrogen escapes more easily than the heavier deuterium. Thus an atmosphere grows steadily richer in deuterium.

*Pioneer* found about 100 times as much deuterium in Venus' atmosphere as in Earth's. The enrich-

ment means that at least 8 meters of water over the entire surface has been lost. That's an ocean of sorts, but the problem with this figure is that no one knows what the initial ratio of hydrogen isotopes was. Moreover, comets are a possible external source of water as well. Therefore, while the deuterium/hydrogen ratio tells us that Venus has lost a lot of water, it can't say whether that water belonged to Venus from the start as an early ocean, or whether the water arrived piecemeal via comets and "wet" asteroids and simply enriched an already torrid carbon dioxide atmosphere.

Spacecraft images of Earth's "little brother" planet, Mars, have given strong evidence for the presence of water. Large Martian outflow channels show clear erosion scars of running water. Yet so far even the best images of Venus show no such features. Scientists are hoping, however, that the high resolution and more complete coverage of *Magellan* will either find such features or rule them out.

*Magellan* has a large job cut out for it. Many of the questions about our somewhat bashful sister planet should have much better answers when the mission is over. We should also expect surprises when we get our first closeup looks at the surface. In fact, scientists already suspect that many of the surface features, such as the coronae, are unique to Venus and completely unlike anything we have seen on other planets.

The task of producing a global geological map of a planet as large as Earth is an enormously challenging one for the planetary science community. However, only such a map will let us begin to unravel the complex geological history of Venus, and obtain clues about when, how, and why Venus and Earth evolved so differently. □

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*R. Stephen Saunders is project scientist for the Magellan mission. He has worked on the project since the 1970s and has also studied planetary geology with the Mariner, Voyager, Pioneer, and Viking missions.*



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by Govert Schilling

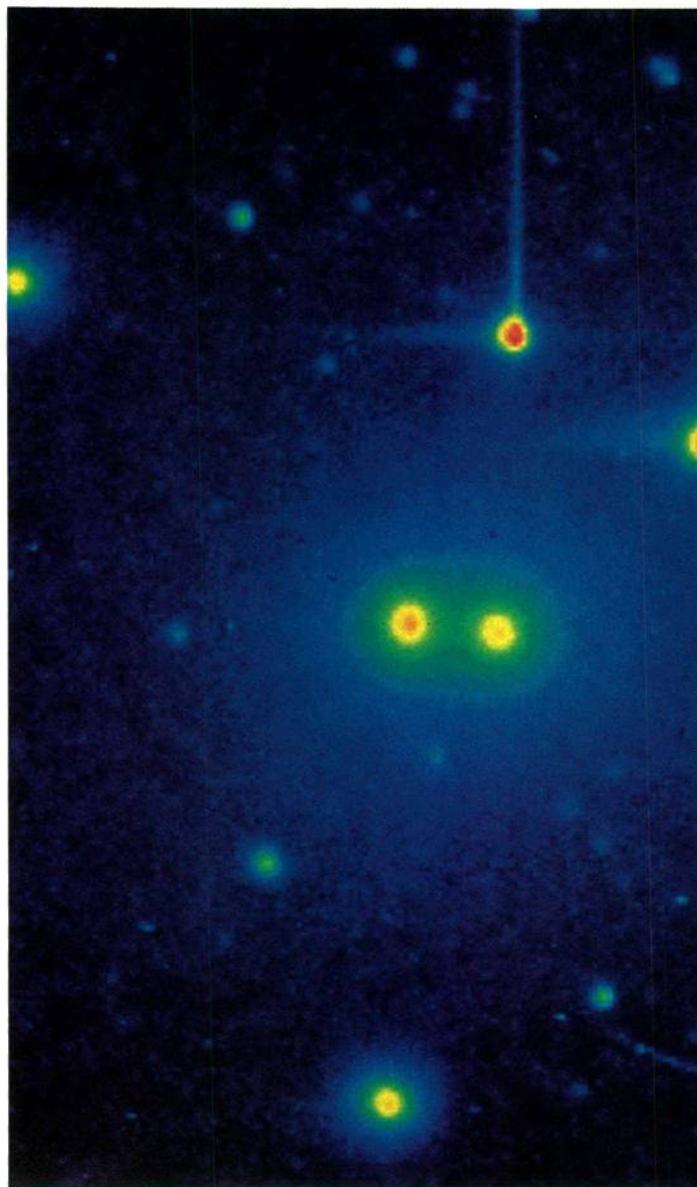
**S**pringtime in the Canary Islands. During the day exotic birds sing from the palms as the turquoise water washes up on the beach. Since 1986 telescopes high atop the islands' Roque de las Muchachos mountains have collected light from distant celestial objects. Tonight an astronomer is using the largest telescope at the observatory, the Anglo-Dutch William Herschel Telescope, to photograph a distant quasar. Once the spectrograph has been placed in the focal plane of the telescope, she aims the telescope by computer. The light from the quasar passes through the telescope and is recorded by an electronic detector.

For the astronomer this is a routine observing run. But what about the light from the quasar? What of its experiences before being captured by the electronic detector on a warm spring night on Earth?

The feeble light our astronomer records left the quasar 12 billion years ago. The particles of light that arrived on Earth tonight began their journey at a time when Earth did not yet exist.

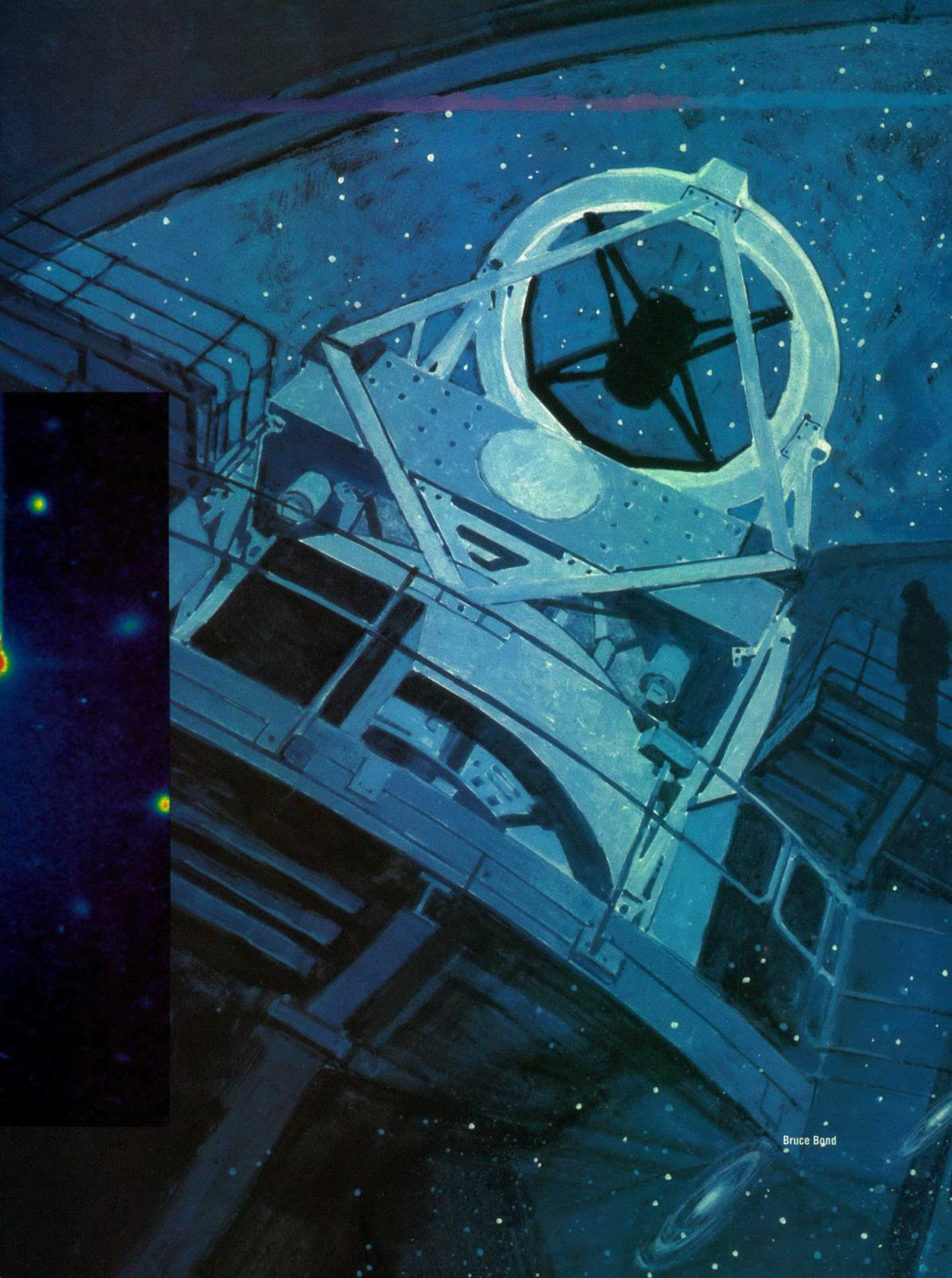
Traveling at 186,000 miles per second, the light from the quasar carried a record of the conditions in a very distant part of the universe. Quasars, discovered nearly thirty years ago as starlike objects with peculiar spectra, appear to be the most distant objects known. Although they are not well understood, quasars are thought to be the highly energetic cores of young galaxies, possibly containing supermassive black holes. In any event, the brightness of quasars at extreme distances means they are tremendously energetic objects. Twelve billion years ago a wave of light from our quasar set out on a journey through space to an unknown destination. After the light left the quasar, many years passed — tens, hundreds, and thousands. The light lost none of its speed. Each second it moved fast enough to circle Earth's equator seven and a half times. But even after ten thousand years of travel, the light still hadn't left the quasar's host galaxy. Only when it emerged from this galaxy did the light's journey between the galaxies begin.

One, two, and three billion years slowly passed. Our own galaxy, the Milky Way, was forming into a spiral-shaped disk in which billions of stars softly turned on. Throughout these billions of years the light from the quasar sped through the emptiness of space. The light passed across vast regions of the universe called supervoids. These areas contain nothing but black, cold space. Then the light passed through clus-



**A LIGHT-SPEED JOURNEY** through vast corridors of space brought the light of a quasar to Earth. From the quasar's point of view reaching Earth was the culmination of an extraordinary flight. NRAO photo.





Bruce Bond





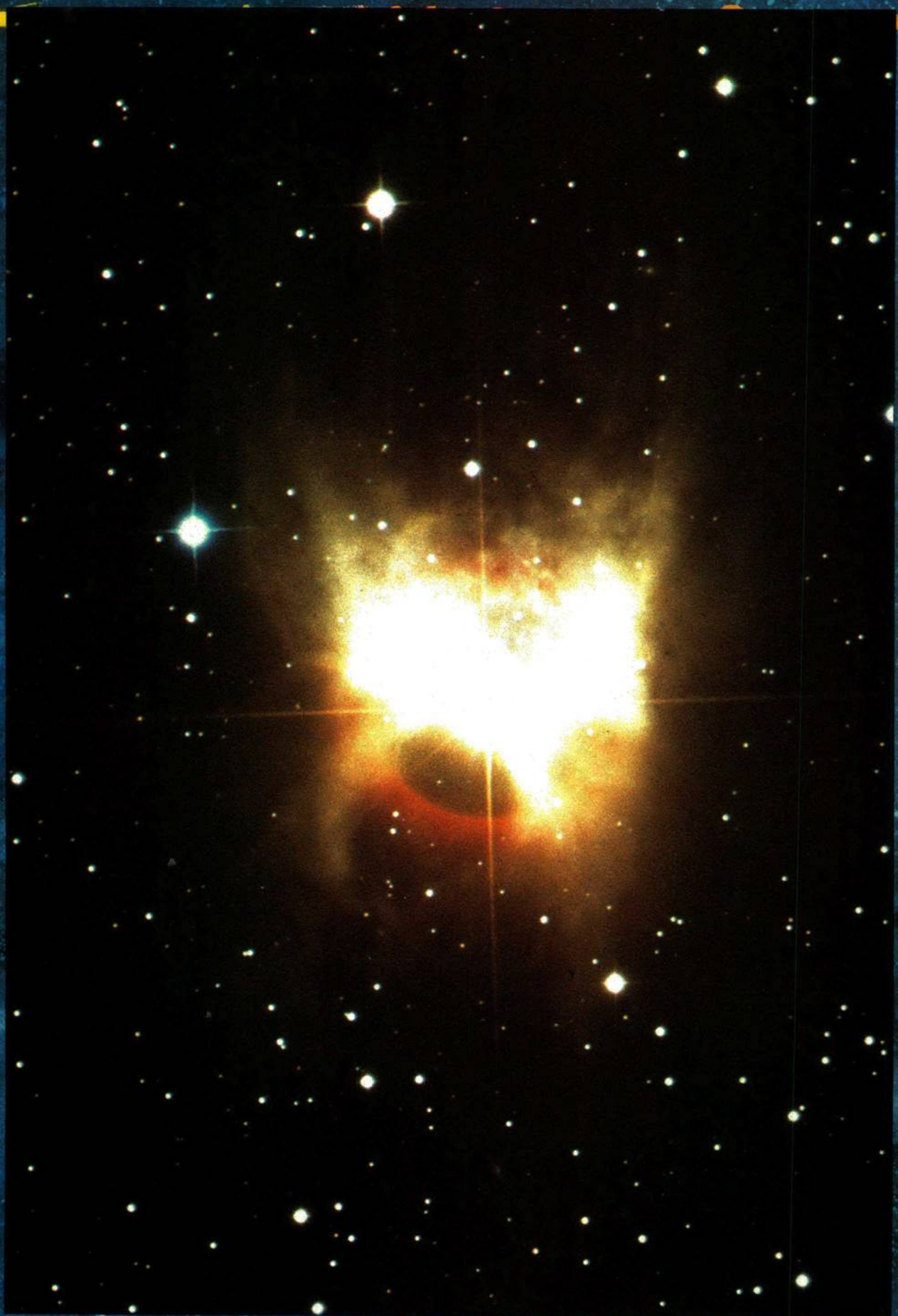
NOAO

A TWELVE-BILLION-YEAR TREK brought the wave of quasar light from the edge of the universe to Earth. As the light passed through the Coma Cluster of galaxies (above) 350 million years ago, life on Earth was diversifying. Fish were numerous and tree-ferns inhabited the shores. As the light passed through nearby galaxies like NGC 4501 (right), dinosaurs encountered rough times in the wake of a dust storm produced by the collision of an asteroid with Earth. Soon thereafter, *Homo habilis* inhabited the trees. Some 10,000 years ago the quasar's light encountered numerous Milky Way objects like IC 2220, the Toby Jug Nebula (opposite page). Early humans gave birth to astronomy as they gazed toward the nighttime sky and wondered about the stars.

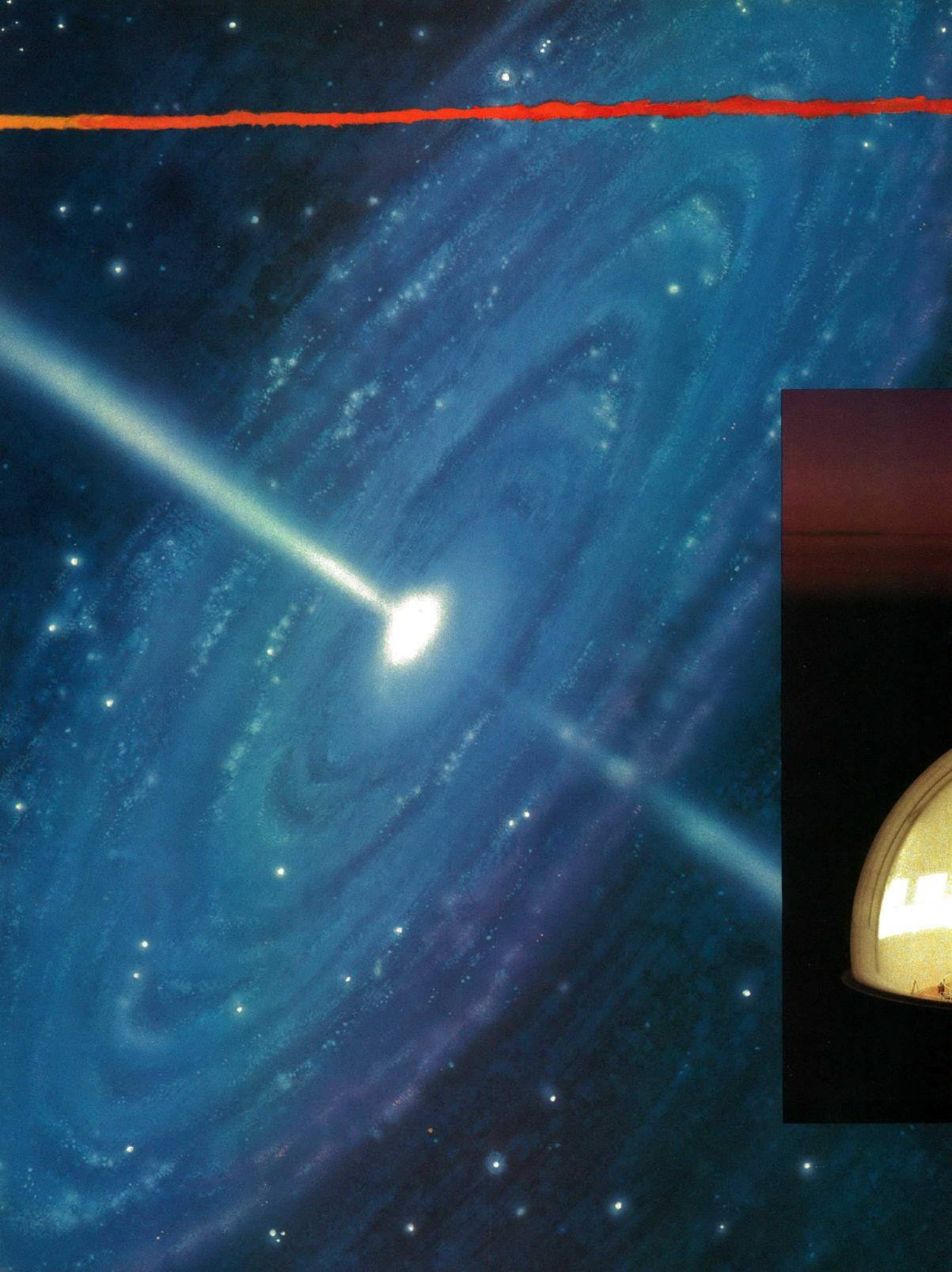


Rudolf Schild, Harvard-Smithsonian Center for Astrophysics



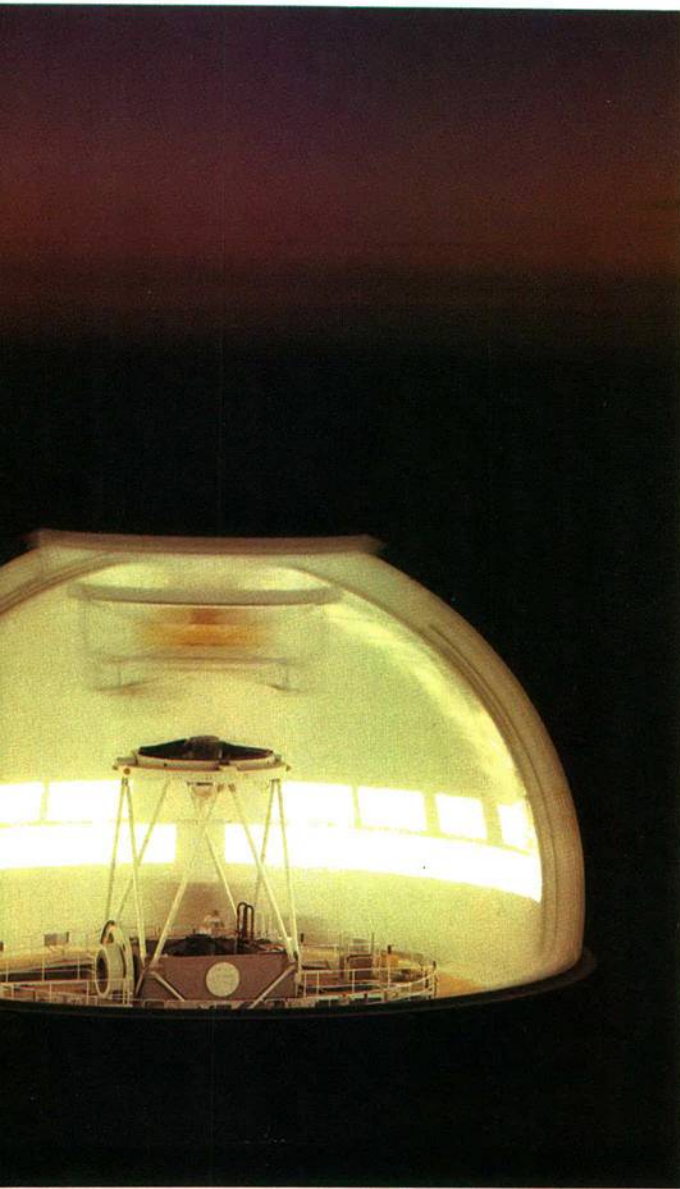








**Twelve billion years ago  
a wave of light from a distant quasar  
set out on a journey through space  
to an unknown destination.**



**GIANT TELESCOPES** like the William Herschel Telescope in the Canary Islands trap ancient light that lets us peer deep back in time toward the very beginning of the universe. Royal Greenwich Observatory photo.

ters or superclusters of galaxies. Every few million years it briefly visited a galaxy. After 6 billion years the quasar's light had covered half the distance to Earth. But in what is now the solar system, there was not yet any trace of Earth or even the Sun.

Seven billion years after the quasar's light was emitted, a cloud of interstellar gas and dust slowly contracted and consolidated, and the Sun and planets formed. During the time Earth formed, the quasar's light passed through a supercluster of galaxies. Five hundred million years later, as the light sped through the darkness of intergalactic space, Earth's first single-celled organisms developed. The evolution of an intelligent and inquisitive mammal had begun.

As life on Earth evolved into multicelled organisms, the light from the quasar relentlessly rushed onward by 6 trillion miles each year. By now the quasar's light had entered our region of the universe. Three hundred fifty million years ago it was about as far away as the Coma Cluster of galaxies. Fifty million years later the quasar's light was closer than the Perseus Cluster of galaxies. On Earth the first amphibians emerged. Numerous fishes inhabited the oceans, and ferns and bracken covered the continents.

To a twentieth-century observer Earth would have been unrecognizable. The present distribution of land and sea bears no resemblance to that of a few hundred million years ago. As the light from the distant quasar approached the Virgo Cluster of galaxies, the primeval continent of Pangaea began to slowly break apart and Earth's crustal plates gradually drifted apart. By now, the quasar's light had journeyed 11.8 billion years — 98.5 percent of the distance to Earth. The journey was nearing its end. Even so, on Earth there was still no sign of mammals. As the continents began to move apart the first dinosaurs were evolving, to be followed only 50 million years later by the first mammals.

Dinosaurs held absolute sway over our planet for tens of millions of years. But their rule came to a sudden end about 65 million years ago when an asteroid or comet hit Earth. The atmosphere was laden with thick clouds of dust for many years. Sunlight was blocked, food chains were broken, and countless species died out. The cosmic catastrophe thus cleared the way for the evolution of mammals. By then, the quasar's light had covered 99.5 percent of the distance to Earth and was in the Virgo Cluster.

The onward-speeding light reached the Local



**We had received a message from an  
incredibly powerful and distant place  
that we will never see exactly the  
same way again.**

Group of galaxies and was soon closer to Earth than the Andromeda Galaxy. On Earth the family of mammals was large and rich in species, from the huge mammoths to the relatively small *Homo habilis* that lived in the trees of extensive tropical forests.

*Homo erectus* appeared as the quasar's light passed the Magellanic Clouds, two small galaxies that revolve about the Milky Way. Later, subtle periodic variations in Earth's orbit caused ice ages that forced *Homo sapiens* to lead a nomadic existence. The light passed the Milky Way's center, leaving a mere 25,000 light-years between the quasar's light and Earth. The light passed stars, star groups, and gas clouds. By the time the light was 10,000 light-years from Earth, the last ice age had come to an end. The quasar's light had covered 99.9999 percent of the distance it would travel. By now there may have been human beings looking up at the night sky, thinking about the thousands of points of light they saw. Astronomy was born.

Civilizations rose and fell. Wars were won and lost yet the problems that created them persisted. People discovered writing and the first records of astronomical observations were made. The quasar's light approached unrelentingly. Greek civilization flowered and the first steps were taken on the path to modern science. At about 500 A.D. the quasar's light passed the Orion Nebula. Eleven hundred years later the light was as close as the Pleiades star cluster, a little less than 400 light-years from Earth. Galileo Galilei became the first person to turn a telescope toward the sky and humanity's discovery of the universe was underway. It was January 1610.

The development of the telescope proceeded alongside astronomy itself. Astronomers such as William Herschel, Charles Messier, and Clyde Tombaugh discovered planets, nebulae, and star clusters. Telescopes got bigger and bigger and mirrors were used to focus starlight rather than just lenses. By 1948 the light from the quasar had passed one of the brightest stars in the sky, Capella. That year the Hale Telescope's 5-meter mirror began probing the skies from Palomar Mountain, California. The moment was fast approaching!

By 1963 the quasar's light was closer than the bright, blue-white star Vega. This was the year astronomer Maarten Schmidt deduced that some unusual radio sources that looked like stars were actually incredibly distant. They came to be called quasistellar

objects, or simply quasars. No one understood how they generated such great amounts of energy. Quasars became the focus of intense research.

Meanwhile, the light from our quasar sped closer. During the summer of 1985, as the Herschel Telescope was being finished, the quasar's light put the last of the stars, Alpha Centauri, behind it. The following year the Herschel Telescope was shipped from Britain to La Palma. Engineers spent months setting up and testing the instrument and each day the light from the distant quasar closed in by more than 16 billion miles. In 1987, the Herschel Telescope saw first light.

Today dawned and the Dutch astronomer prepared to observe the quasar. By noon she had checked all the details of the observing run. At midafternoon the quasar's light passed a small unmanned spacecraft traveling beyond the orbit of Pluto. It was *Pioneer 10*, a probe launched from Earth in 1972. *Pioneer 10* had spent eighteen years moving out of the solar system at a speed of 16 miles per second. But the quasar's light would cover the distance of *Pioneer 10*'s journey in just a few hours.

By early evening the quasar's light had crossed Pluto's orbit. At 9:15 p.m. the light crossed the orbit of Uranus, and at 10:30 it traversed Saturn's orbit. Forty-five minutes later the light passed inside Jupiter's orbit. At that moment the astronomer placed the spectrograph into the telescope's focal plane. She then left the dome to take a five-minute coffee break, during which time the light from the quasar hurtled some 60 million miles closer. The quasar's light shot past the Moon and spilled onto the floor of the dome. The astronomer moved the telescope and the light entered the telescope. After twelve billion years the quasar's light struck the astronomer's light-sensitive detector.

Another observation in an endless routine of data collecting, the astronomer thought. But in reality it was the end of a momentous journey, a trip through clusters and supervoids, past galaxies, nebulae, and solitary stars. We had received a message from an incredibly powerful and distant place that we will never see exactly the same way again. □

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*This article is based on material from *Dimensies in de Natuur* by Wilfred Kruit and Govert Schilling (Aramith Publishers, Amsterdam, 1987). It was translated from Dutch by Rosalind Melis.*



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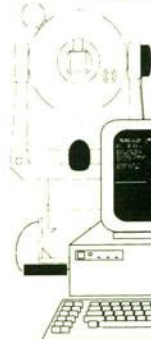
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## ASTROPHOTO OF THE MONTH



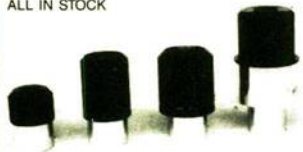
The "Flame Nebula" NGC 2024 in Orion. Also known as the "Christmas Tree" or the "Tank Trucks" nebula. NGC 2024 is seen best usually with either a LUMICON DEEP-SKY or UHC filter. Photo by Don N. Reiners, 16" f/5, 40 min. using hypered 2415 film and a LUMICON 2" EASY-GUIDER.

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# Where Are the Solar Neutrinos?

Physicists predict that the Sun should be producing far more neutrinos than astronomers have been able to observe.

by John N. Bahcall

Every second of every day the Sun converts 600 million tons of hydrogen into helium. This alchemy produces enormous amounts of energy, energy that eventually works its way to the Sun's surface and emerges as light and heat. The same nuclear reactions that produce this energy also produce extremely elusive particles called neutrinos that easily escape the Sun. These emissaries from the core allow astronomers to "see" deep inside the Sun and to examine the energetic physical processes that occur there.

Neutrino astronomy is interesting largely because neutrinos are so elusive that they can reach us from otherwise inaccessible regions where photons, the traditional messengers of astronomy, are trapped. Yet neutrinos, and particularly solar neutrinos, are observationally scarcer than they should be. For more than twenty years now astronomers and physicists have debated why we don't see as many neutrinos streaming from the Sun as theory predicts.

For astronomers and physicists alike, the missing neutrinos raise important questions that cut to the heart of their science. How does the Sun shine? Does the neutrino have a mass? Can solar neutrinos be used to test the theory of stellar evolution? Can solar neutrinos be used to explore the unification of the strong, weak, and electromagnetic forces? These are just some of the questions that motivate the study of neutrino astronomy.

A neutrino is an elementary particle that interacts only very rarely with other matter and travels at or very near the speed of light. There are three known types of neutrinos — the electron neutrino, the muon neutrino, and the tau neutrino — each of which is associated with a subatomic particle known as a lepton. Leptons are elementary particles that experience three of the four fundamental forces in the universe (the weak nuclear force, the electromagnetic force, and gravity) but not the strong nuclear force.

If astronomers have correctly calculated what is happening inside the Sun, then the discrepancy between the calculated and observed rates of neutrino events may be caused by some previously unknown physics that affects neutrinos during their journey from the Sun to Earth. If, on the other hand, the conservative physicist is correct that neutrinos are unaffected by their Sun-to-Earth journey, then astronomers may not have calculated accurately the characteristics of the solar interior. Who is right?

## What's at Stake

For astronomers, solar neutrino experiments rigorously test their theories of how energy is generated in stars and how stellar evolution works. Fortunately, these tests are independent of many of the uncertainties that complicate comparing theory to observations of stellar surfaces. For example, astronomers think that convection and turbulence play important roles near the surfaces of stars but are unimportant in the solar interior. Furthermore, the effects of rotation and magnetic fields, which are hard to model accurately, further complicate the analysis of observations of stellar surfaces.

Observations of solar neutrinos also test stellar evolution theory. Because we know more about the Sun than about any other star, we should be able to calculate what the Sun is doing more accurately than we can the behavior of less familiar stars or stars that are evolving rapidly. We know the Sun's mass, its luminosity, its surface chemical composition, and its age much more accurately than we can determine these crucial parameters for any other star. The Sun is also in the simplest stage of stellar evolution. According to standard theory, it is a middle-aged main-sequence star, calmly converting hydrogen into helium without violent or rapid evolution.

One possible solution to the solar neutrino problem is to change the current theory of stellar evolution. But the proposed modifications would force a change in conventional ideas about how stars evolve, ideas that astronomers use every day in their research. Astronomers use stellar evolution theory to determine the ages of stars, to interpret stellar compositions, to infer

**Solar neutrino experiments rigorously test astronomers' theories of how energy is generated in stars.**

*This article is adapted from chapter 1 of Neutrino Astrophysics by John N. Bahcall (Cambridge University Press, 1989).*



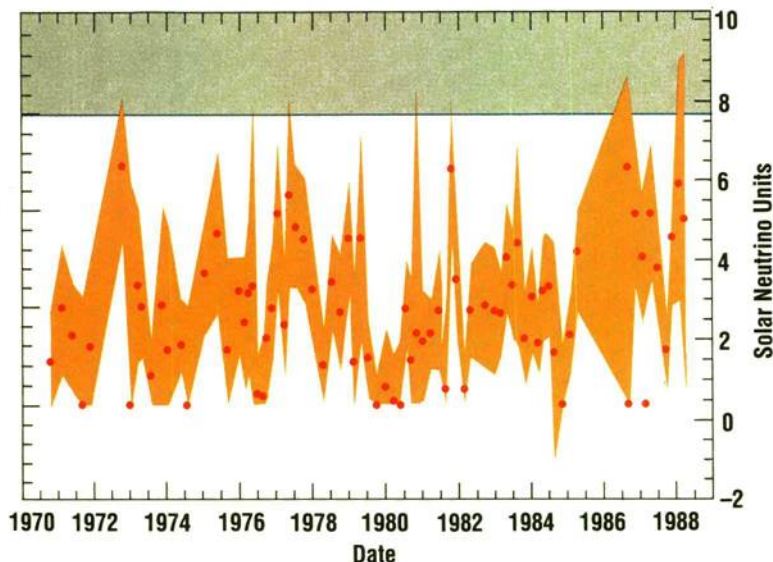


**SHOOTING STRAIGHT** from the heart of the Sun, neutrinos bring astronomers vital information about the nuclear reactions occurring there. Illustration by MariLynn Flynn.



the evolution of galaxies, and to place limits on the chemical composition of the primordial material of the universe. Each of these basic astronomical "industries" is called into question by at least one of the proposed solutions of the solar neutrino problem. Furthermore, none of the solutions is fully consistent with well-established physics.

From the physicists' point of view, solar neutrino experiments provide a special opportunity to explore the weak nuclear force. Interactions involving the weak force are responsible for converting protons into neutrons and are therefore essential for the nuclear reactions that convert hydrogen into helium in the Sun. Experiments that use the Sun as a source of neutrinos



**FAR FEWER SOLAR NEUTRINOS** have been observed in Raymond Davis' experiment (red dots) than theoreticians predict (blue line). Error limits are shown in beige.

are up to 10 million times more sensitive than corresponding laboratory or atmospheric experiments. One reason is that some effects of the weak interaction take a relatively long time to occur. Because solar neutrinos travel a long distance on their way to Earth, the weak interactions have a longer time to make their effects felt than in terrestrial experiments. In addition, solar neutrinos can be used to probe weak interactions at lower energy levels than are possible with laboratory experiments.

Solar neutrinos also offer a way to test the new grand unified theories of physics. During the past twenty years physicists have developed a theory known as the electroweak theory that describes electromagnetic and weak interactions as different manifestations of the same underlying force. In the standard version of electroweak theory all neutrinos have masses equal to zero. However, in the grand unified theories, which attempt to combine the strong nuclear force with the weak and electromagnetic forces, neutrinos naturally have a non-zero mass. In fact, the predicted values for neutrino masses differ substantially from one grand unified theory to the next. Over much of this mass range, the only way known to test the various theoretical models is with solar neutrino experiments.

## Observation versus Prediction

The solar neutrino problem can be stated simply. The number of solar neutrinos detected on Earth is less than one-third as many as expected based on the most accurate theoretical calculations of how the Sun generates energy. For two decades the only operating solar neutrino experiment was one designed by Raymond Davis, Jr., of the University of Pennsylvania and his collaborators. Their neutrino "telescope" is a tank about the size of an Olympic swimming pool containing 100,000 gallons of cleaning fluid (perchloroethylene) located deep underground in the Homestake Gold Mine in Lead, South Dakota.

Both the theoretical and the observational results for Davis' solar neutrino experiment are expressed in terms of the solar neutrino unit, or SNU (pronounced "snew"). The predicted rate for capturing solar neutrinos in the perchloroethylene tank is  $7.9 \pm 2.6$  SNU. The observed rate is  $2.2 \pm 0.3$  SNU.

The discrepancy between the predicted and observed rate was confirmed recently by an independent technique using the U.S.-Japan neutrino detector, Kamiokande II. The detector contains 2,140 tons of pure water and is located in a mine in the Japanese Alps. Preliminary results from this experiment indicate that only about 45 percent of the higher-energy neutrinos predicted are actually seen.

The predictions for both the Davis and Kamiokande II experiments are valid for the combined standard model of physics and astronomy. That model combines the standard physics theory that describes both electromagnetic and weak interactions (the electroweak theory) and the standard astronomical model of the Sun.

At this point you might well ask if the solar neutrino problem isn't overblown. When you take into account the uncertainties in the predicted and observed rates, the lowest allowed theoretical value (5.3 SNU) is less than two times the largest allowed experimental value (3.1 SNU). But though the difference between theory and observation is not large, the ratio of the difference to the uncertainties is significant. Even if you simultaneously push the theory and the observations to the extreme limits set by their known uncertainties, as the skeptic would do in comparing 5.3 SNU with 3.1 SNU, the standard calculations and the observations do not overlap. The solar neutrino problem differs from many puzzles in astronomy in that we know more about the Sun than about any other star. If we can't calculate accurately how the Sun shines, then we should be cautious in claiming to understand more complicated astronomical systems.

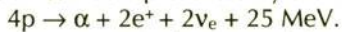
The discrepancy between observation and calculation has resisted the combined efforts of thousands of scientists to explain it. Some have remeasured nuclear physics parameters and other quantities used in the calculations. Others have reevaluated theoretically determined quantities. Yet the discrepancy remains.

The solar neutrino problem may be the first indication that scientists need to develop either new astrophysics to explain how the Sun shines or new subatomic physics to explain the behavior of the neutrino. That's why the stakes are so high for the practitioners of both disciplines, and why everyone is anxious to know whether the astronomer or physicist is right.



## The Sun's Interior

For astronomers to get a handle on the solar neutrino problem, they need to understand what is going on inside the Sun today. And to understand that, they need to apply the theory of stellar evolution to the Sun. Astronomers know that the Sun evolves because they observe light radiating from its surface. This loss of light from the solar surface is in turn balanced by the burning of protons (the nuclei of normal hydrogen atoms) into alpha-particles (the nuclei of normal helium atoms) in the core of the Sun. The overall nuclear-fusion reaction can be represented by the relation:



Four protons are converted to one alpha-particle ( $\alpha$ ), two positrons ( $e^+$ , positive electrons), and two electron neutrinos ( $\nu_e$ ), with a release of about 25 million electron volts of thermal energy. Each conversion of four protons to an alpha-particle is known as a "termination" of the chain of energy-generating fusion reactions. The thermal energy supplied by nuclear fusion ultimately emerges from the surface of the Sun as sunlight after a long, tortuous journey that lasts roughly 10 thousand years.

A standard solar model of how the Sun behaves today is the end product of a sequence of models describing the Sun at earlier times. The calculation of a model begins with the description of a main-sequence star that has a homogeneous composition. Hydrogen burns in the star's core, which supplies both the star's luminosity and the thermal pressure that supports the star against the force of gravity. Each successive model is calculated by allowing the composition to change as a result of the nuclear reactions and by allowing slight changes in other parameters. The models that describe later times in an evolutionary sequence have inhomogeneous compositions. In the model for the current Sun, the fraction of hydrogen by mass in the core is about half that at the surface.

The physical conditions in the Sun's interior, where the neutrinos are produced, are different from the conditions of everyday life, but they are not so different as to suggest that the relevant physics holds significant surprises. The heat and density in the Sun's core is high enough for the positively charged nuclei to overcome their mutual repulsion and fuse together. The central temperature is about 15 million kelvins and the central density is about 150 times the density of water. As far as we know, the physics that governs the behavior of the gaseous solar interior is relatively simple.

Astronomers assume that the initial chemical composition of the Sun was approximately the same everywhere and that the present-day surface composition reflects the initial ratio of heavy elements to hydrogen. The surface of the Sun is too cool to support the nuclear reactions that could have significantly altered the initial composition.

The calculation of a standard solar model begins with an estimate of the initial fraction of the Sun's total mass that was in the form of hydrogen. Unfortunately,

the abundance of helium on the solar surface can't be measured accurately so surface measurements can give only the abundances of elements heavier than helium relative to hydrogen. The model Sun evolves as its composition changes and as nuclear reactions release energy. The interior calculations must be carried out with much greater accuracy than in most other applications of stellar evolution theory because the neutrino measurements relate directly to processes occurring in the Sun's interior and the calculated fluxes are sensitive to the physical conditions.

A number of different research groups have developed computer codes for calculating the Sun's evolution. When they are adjusted for differences in the initial parameters, the codes yield individual solar neutrino fluxes that are the same to within an accuracy of about 10 percent or better.

The theory of stellar evolution agrees rather well with conventional astronomical observations of the Sun and other stars. The standard solar model gives a satisfactory, although necessarily incomplete, account of what is known about the Sun from observing light emitted at the Sun's surface. Such observations are often sensitive to what is happening in

the outer, less well-understood layers of the Sun where material moves around on relatively short time scales. Astronomers don't believe that the corresponding uncertainties are as important in the Sun's interior, where the material is more stably stratified.

The theory of stellar evolution has a number of successes to its credit. Its most basic achievement is in the theoretical relationship between stellar mass and luminosity. For the vast majority of stars this relationship agrees with observations over a factor of 100 in mass and 1 million in luminosity.

But the greatest achievement of stellar-evolution theory is so overwhelming that it is usually overlooked. Astronomers routinely use the theory to interpret astronomical observations of the physical and chemical characteristics of individual stars of widely different types in a variety of environments in both nearby and distant galaxies. Stellar evolution theory has been remarkably successful in providing a framework for discussing these traditional astronomical observations without obvious inconsistencies.

The bottom line is that only the solar neutrino experiments of Raymond Davis and Kamiokande II conflict with the standard theory. Even this could be just an apparent inconsistency if new physics is required to describe what happens to neutrinos on their way from the interior of the Sun to terrestrial detectors. Many imaginative theoretical physicists have proposed that solar neutrinos are produced in the quantity predicted by the standard solar model, but that they do not reach Earth in the same form in which they are created. If something happens to the neutrinos in the solar interior or on their way to Earth, then the standard solar model may be correct and the solar neutrino experiments could be telling us something new about neutrino propagation over large distances.

**Neutrinos generated by nuclear fusion reactions in the Sun travel to Earth in eight minutes. Light released in those reactions takes 10,000 years.**



## Nuclear Fusion and Neutrino Production

About 600 million tons of hydrogen are burned in the Sun's nuclear furnace every second to make the Sun shine as brightly as it does. Nuclear physicists have worked for half a century to determine the details of this transformation of matter into energy. The main nuclear burning reactions in the Sun, as shown in the table below, represent the energy-generating chain known as the proton-proton chain. This table also indicates the relative frequency with which each reaction occurs in the standard solar model.

The fundamental reaction in the solar energy-generating process is the proton-proton reaction. In this reaction a proton changes to a neutron in the vi-

gamma ray (reaction 4). The neutrinos formed after this process are the ones primarily detected in the perchloroethylene neutrino experiment. The  ${}^7\text{Be}$  nucleus nearly always captures a free electron (reaction 5). This branch produces neutrinos with energies of 0.9 MeV (90 percent of the time), which contribute a small but non-negligible fraction of the neutrinos the standard model predicts should be captured in the perchloroethylene and gallium experiments. There is no experiment in progress that isolates the contribution of the  ${}^7\text{Be}$  neutrinos, although some suggestions for practical detectors have been made.

The standard model predicts that most of the neutrinos captured in the perchloroethylene experiment should come from the rare termination in which  ${}^7\text{Be}$  captures a proton to form a radioactive boron nucleus,  ${}^8\text{B}$  (reaction 7). The  ${}^8\text{B}$  decays to the unstable beryllium isotope  ${}^8\text{Be}$ , ultimately producing two alpha-particles, a positron, and a neutrino. The neutrinos from the  ${}^8\text{B}$  decay have a maximum energy of less than 15 million electron volts. Although the reactions involving  ${}^8\text{B}$  occur only once in every 5,000 terminations of the proton-proton chain, the total calculated event rates for the perchloroethylene and Kamiokande II experiments are dominated by this rare mode.

### Capturing the Neutrino

Once they are produced, the neutrinos fly out of the Sun at or near the speed of light. A small percentage of them pass through a tank of cleaning fluid a mile below the surface of South Dakota.

Very rarely one of the neutrinos reacts with a chlorine atom in the tank, producing an electron and a radioactive argon atom. Every few months for the past twenty years Davis and his collaborators extracted a small sample of radioactive argon ( ${}^{37}\text{Ar}$ ), typically about 15 atoms, out of the total of more than  $10^{30}$  atoms in the tank. The  ${}^{37}\text{Ar}$  produced in the tank is separated chemically from the perchloroethylene, purified, and counted in low-background proportional counters. Experiments show that the researchers have extracted over 90 percent of the  ${}^{37}\text{Ar}$  produced in the tank.

The average rate at which  ${}^{37}\text{Ar}$  is produced in the tank is  $0.46 \pm 0.04$  atoms per day, of which a small part is background (due primarily to high-energy cosmic rays that manage to penetrate through the earth above the tank). Subtracting the known background rate from the production rate yields the capture rate of  $2.2 \pm 0.3$  SNU, which is due to solar neutrinos if all of the significant contributions to the background have been recognized.

Of the eight solar neutrino units predicted, six are contributed by the  ${}^8\text{B}$  neutrinos. The difference between the measured values shown on page 42 and 8 SNU is the solar neutrino problem.

For the chlorine experiment the  ${}^8\text{B}$  contribution is most important because many of the neutrinos produced in the boron decay are energetic enough to excite a favored transition between the ground state of  ${}^{37}\text{Cl}$  and a particular state of  ${}^{37}\text{Ar}$  that closely resembles the ground state of  ${}^{37}\text{Cl}$ . None of the more abundant neutrinos have enough energy to cause this transition. A theoretical calculation originally showed that the sensitivity for the detection of  ${}^8\text{B}$  neutrinos is increased by about a factor of twenty by transitions to excited states of  ${}^{37}\text{Ar}$ . This theoretical result has been confirmed by a series of nuclear physics experiments.

## The Proton-Proton Chain in the Sun

| Reaction                                                        | Number | Termination % | $\nu$ Energy (MeV)         |
|-----------------------------------------------------------------|--------|---------------|----------------------------|
| $p + p \rightarrow {}^2\text{H} + e^+ + \nu$                    | 1      | 100           | $\leq 0.420$               |
| ${}^2\text{H} + p \rightarrow {}^3\text{He} + \gamma$           | 2      | 100           |                            |
| ${}^3\text{He} + {}^3\text{He} \rightarrow \alpha + 2p$         | 3      | 85            |                            |
| or, ${}^3\text{He} + \alpha \rightarrow {}^7\text{Be} + \gamma$ | 4      | 15            |                            |
| ${}^7\text{Be} + e^- \rightarrow {}^7\text{Li} + \nu$           | 5      | 15            | 0.861 (90%)<br>0.383 (10%) |
| ${}^7\text{Li} + p \rightarrow 2\alpha$                         | 6      | 15            |                            |
| or, ${}^7\text{Be} + p \rightarrow {}^8\text{B} + \gamma$       | 7      | 0.02          |                            |
| ${}^8\text{B} \rightarrow {}^8\text{Be} + e^+ + \nu$            | 8      | 0.02          | $< 15$                     |
| ${}^8\text{Be} \rightarrow 2\alpha$                             | 9      | 0.02          |                            |

**Termination %:** Percentage of conversions of four protons to one alpha-particle in which the reaction occurs. **Key:** p = proton;  $e^-$  = electron;  $e^+$  = positron;  $\nu$  = electron neutrino;  $\gamma$  = gamma-ray;  ${}^2\text{H}$  = deuterium;  $\alpha$  = normal helium;  ${}^3\text{He}$  = light helium; Be = beryllium; Li = lithium; B = boron

cinity of another proton and forms heavy hydrogen, which is called deuterium ( ${}^2\text{H}$ ). This reaction (number 1 in the table) produces the great majority of solar neutrinos. However, these neutrinos have energies below the detection thresholds for both the perchloroethylene and Kamiokande II experiments. Experiments in progress in the Soviet Union and in Europe using gallium as a neutrino detector are primarily sensitive to neutrinos generated in the proton-proton reaction. The deuterium produced by these reactions burns quickly by a reaction that forms  ${}^3\text{He}$ , a light version of a helium nucleus that contains only one neutron (reaction 2). Reactions 1 and 2 occur in essentially all terminations of the proton-proton chain in the Sun. The richness and complications of the proton-proton cycle begin at the next stage.

According to the standard solar model, 85 percent of the time the proton-proton chain terminates when two  ${}^3\text{He}$  nuclei fuse to form an alpha-particle plus two protons (reaction 3). No additional neutrinos are formed in this reaction.

About 15 percent of the time, however, a  ${}^3\text{He}$  nucleus captures an already existing alpha-particle to form a radioactive beryllium nucleus,  ${}^7\text{Be}$ , plus a



The Kamiokande II experiment detects light emitted by electrons that are pushed in the forward direction by solar neutrinos. This is the first of several experiments that are either in progress or planned in which the interaction of neutrinos with electrons will be used to observe solar neutrinos.

Unfortunately, the scattering experiments can only detect the higher-energy  $^8\text{B}$  neutrinos (those with energies greater than 7 MeV). However, the scattering provides important additional information about the neutrinos that is not available with other types of detectors. Neutrino-electron scattering experiments furnish information about the incident neutrino energy spectrum, the direction from which the neutrinos arrive, and the precise time of each event.

Although the Kamiokande II experiment has been operating for a much shorter time than the chlorine experiment, it has provided astronomers with an important breakthrough. Significantly more neutrinos have entered the detector coming from the direction of the Sun than from any other direction. This experimental result shows for the first time that most of the neutrinos observed on Earth are actually produced in the Sun.

#### Easy and Tough Ways Out

Is there really a solar neutrino problem? The answer is "Yes" if the difference between the number of predicted and observed neutrino events exceeds the range of the uncertainties. The answer is "No" if the uncertainties exceed the difference between theory and observation.

The flux of neutrinos from the initial reaction in the nuclear fusion chain (reaction 1) can be calculated to an estimated accuracy of 2 percent using the standard solar model. Thus the proton-proton flux, the dominant flux of solar neutrinos, can be used for physics experiments on the propagation of neutrinos over astronomical distances.

The production rate for the rare neutrinos from radioactive boron ( $^8\text{B}$ ) decay is sensitive to conditions in the solar interior because the repulsion between the positively charged  $^7\text{Be}$  and the protons is much larger than the average energy of the nuclei in the Sun's core. The calculated flux of  $^7\text{Be}$  electron-capture neutrinos is intermediate in sensitivity between the proton-proton and the  $^8\text{B}$  neutrinos.

In order to predict the event rate in a given detector we must combine theoretical uncertainties with statistical (and systematic) errors in measured quantities. In doing so we have adopted one cardinal rule: Errors associated with different sources are combined so that the total uncertainty is equal to the square root of the sum of the squares of the individual uncertainties.

Two independent experiments using very different techniques have yielded a measurement of the solar neutrino flux that is different from the reliable theoretical value calculated using the standard solar model. Astronomers, chemists, and physicists have analyzed and reanalyzed different elements of this problem trying to make it go away. So far no one has succeeded. Many apparently easy ways out have been tried:

changing the model of the Sun, altering nuclear physics parameters, hypothesizing flaws in the experiments. Each has been checked and found to be implausible. We seem to be stuck with a puzzle that requires a revision of something fundamental.

#### Who is Right?

In textbooks and in popular accounts of science, surprising phenomena are explained in terms of accepted physical concepts. This is not the way science is done in practice. A closer analogy is that we stumble around in a dark, labyrinthine corridor that is only partially lit by insights and data until somehow, after many false turns, we finally arrive at the correct way out. We are sustained by the conviction that there is a

way out, that with more data and with more insights we will ultimately understand the way nature works. Scientific puzzles can last for decades or longer, but the great joy and beauty of science is that well-defined puzzles such as the solar neutrino problem eventually yield their solutions to the scientific method.

Progress in solar neutrino research requires new experiments. There are a plethora of interesting theoretical explanations of the solar

neutrino problem that are consistent with the existing data. New measurements are necessary to determine which solution nature has adopted. Observations need to be made with different detectors and techniques in order to test theoretical predictions and to eliminate the possibility that systematic uncertainties influence the interpretations. Some of the most promising experiments include measurements to be carried out in the Soviet Union and in Europe using many tons of gallium, a joint Canadian-American-English experiment with a thousand tons of heavy water, and a Los Alamos National Laboratory experiment using molybdenum atoms shielded from atmospheric phenomena by the covering of a deep mine.

There are two classes of "solutions" to the solar neutrino problem, those that modify the astrophysical description of the Sun in order to obtain a nonstandard solar model (the "physicists-are-right" approach) and those that hypothesize properties of neutrinos in order to obtain a nonstandard theory of electroweak interactions (the "astronomers-are-right" approach). Hundreds of examples of solutions of the two classes have been published. They can be distinguished experimentally by measuring the numbers of neutrinos of different energies that reach Earth from the Sun.

The first quarter century of solar neutrino astronomy has produced a well-defined "solar neutrino problem." Experiments to be performed in the next decade may reveal the solution to this problem and point us toward either a more complete theory of stellar energy generation or of neutrino propagation. If we are lucky, solar neutrino experiments might do both. □

---

*John N. Bahcall is professor of Natural Science at the Institute for Advanced Study in Princeton, New Jersey. He is currently president-elect of the American Astronomical Society.*

**Solar neutrino experiments are the only observations that conflict with the standard theory of what is happening in the Sun.**







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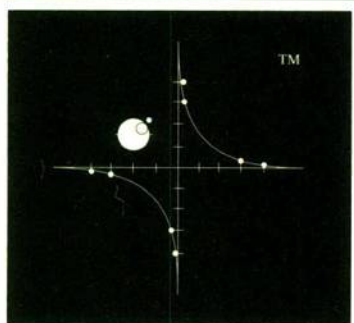
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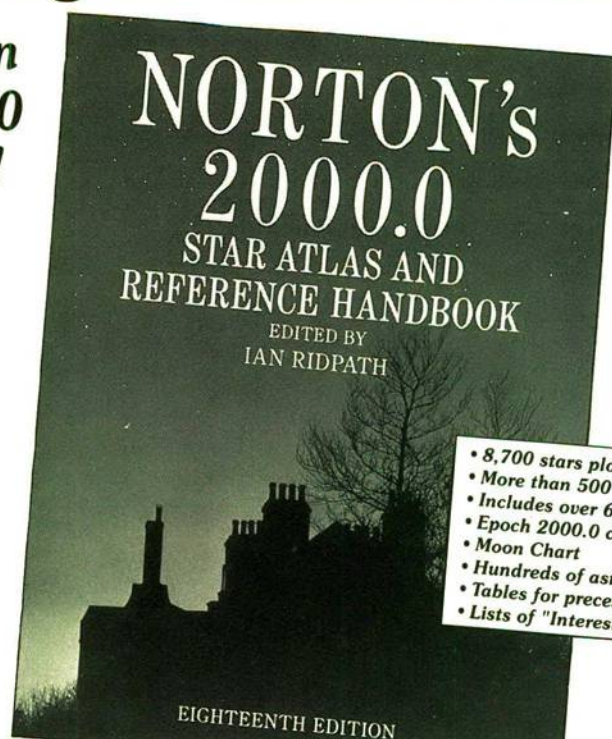




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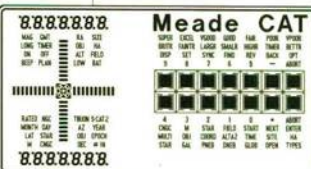
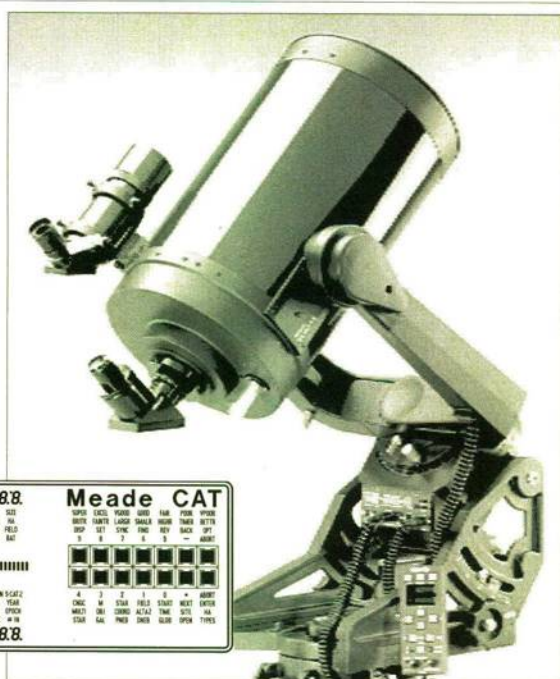
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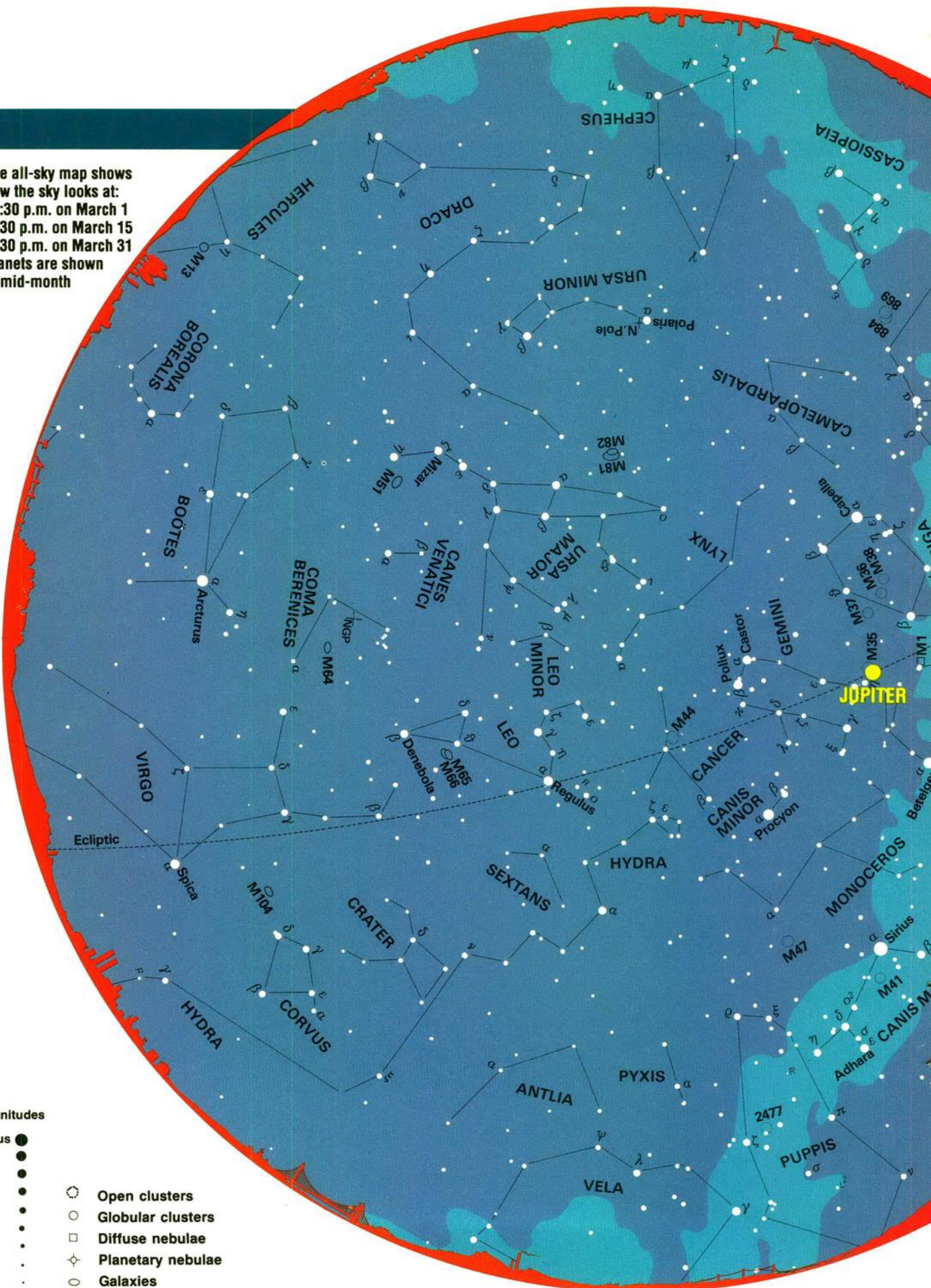
North

The all-sky map shows  
how the sky looks at:  
10:30 p.m. on March 1  
9:30 p.m. on March 15  
8:30 p.m. on March 31  
Planets are shown  
at mid-month

East

# Magnitudes

- |          |                     |
|----------|---------------------|
| Sirius ● | Open clusters ○     |
| 0.0 ●    | Globular clusters ○ |
| 0.8 ●    | Diffuse nebulae □   |
| 1.6 ●    | Planetary nebulae ◇ |
| 2.4 ●    | Galaxies ○          |
| 3.2 ●    |                     |
| 4.0 ●    |                     |
| 4.8 ●    |                     |
| 5.6 ●    |                     |





# Sky Almanac

March 1990

## ACTIVE SUN COULD MEAN AURORAE

Keep a close watch on the night sky for the ghostly aurora borealis over the next few months. With the Sun expected to reach its highest level of activity in at least the past eleven years, our chances of seeing an aurora are significantly better than normal.

## VENUS AT GREATEST ELONGATION

The brightest planet of all, Venus, is at its farthest position west of the Sun at the end of March. Look for the  $-4.5$ -magnitude planet low in the southeast about an hour before sunrise.

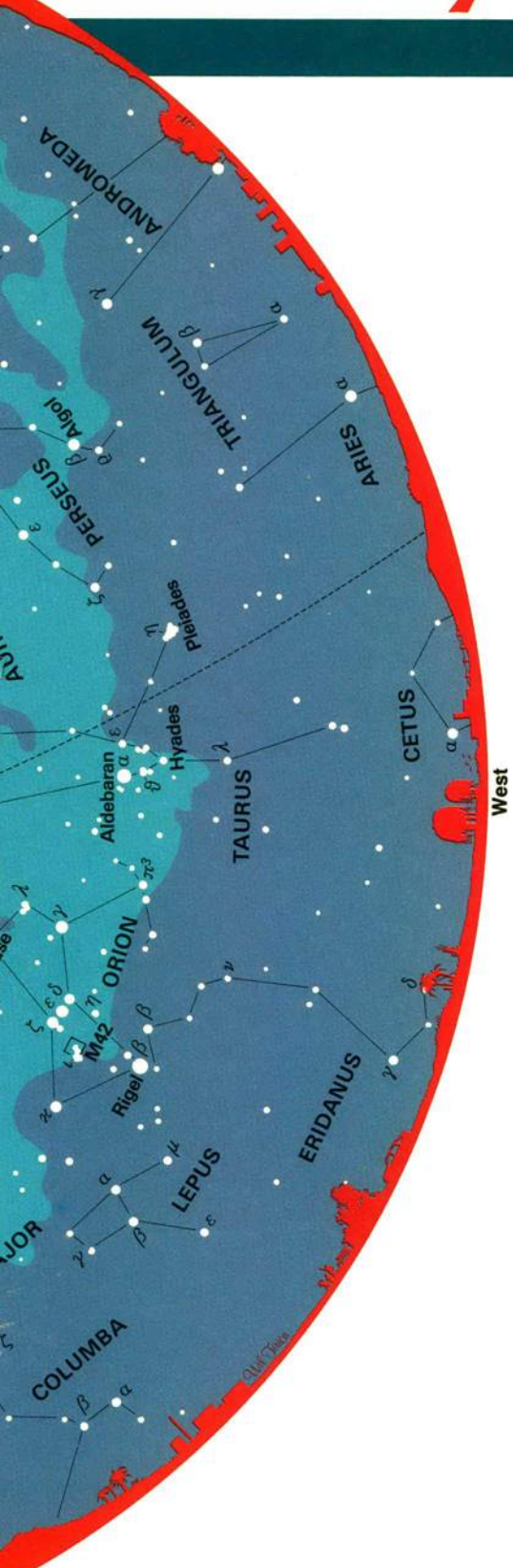
## TWO INTERESTING OCCULTATIONS

The waxing crescent Moon traverses the northern part of the Pleiades star cluster on the evening of March 2, making for a fine view in binoculars or a telescope. You'll need a telescope to see the rare daylight occultation of Mars on March 22, an event visible from most of western and central North America.

## JUPITER'S SPECTACULAR SATELLITES

Observe Jupiter's Galilean satellites this month. With Jupiter at quadrature, eclipses of the moons and transits of the moons' shadows take place with the moons farther from Jupiter's disk than usual.

## Dates and Times

- 
- 2** The Pleiades is occulted by the Moon, 11 p.m. EST
  - 3** First Quarter Moon is at 9:05 p.m. EST
  - 4** The Moon passes  $1.1^\circ$  south of Ceres, 3 p.m. EST
  - 5** The Moon passes  $4^\circ$  north of Jupiter, 4 a.m. EST
  - 11** Full Moon is at 5:58 a.m. EST
  - 12** Vesta is in conjunction with the Sun
  - 16** The Moon is at apogee (251,789 miles from Earth), 2:50 a.m. EST
  - 17** The Moon passes  $0.2^\circ$  south of Antares, 7 p.m. EST
  - 19** Last Quarter Moon is at 9:30 a.m. EST  
Mercury is in superior conjunction
  - 20** Vernal equinox is at 4:19 p.m. EST
  - 21** The Moon passes  $2^\circ$  south of Saturn, 9 a.m. EST
  - 22** Mars is occulted by the Moon, 1 p.m. EST
  - 23** The Moon passes  $2^\circ$  south of Venus, 2 a.m. EST
  - 26** New Moon is at 2:48 p.m. EST
  - 27** Thalia is at opposition
  - 28** The Moon is at perigee (224,040 miles from Earth), 3:08 a.m. EST
  - 30** Venus is at greatest western elongation ( $46^\circ$ )



### **AN AURORA ALERT**

With the Sun now reaching a peak in activity, you have a better-than-average chance of seeing the aurora borealis, or northern lights. Auroral displays can range from faint amorphous glows low in the north to bright, colorful bands and arcs that stretch across the sky. These fascinating lights are seen most often at far-northern latitudes, such as the northern United States, Canada, and northern Europe. Occasionally, however, the aurora can be seen from much farther south particularly when the Sun is near the height of its 11-year cycle of activity, as it is now.

Brighter aurorae often exhibit distinct colors, with shades of blue, yellow-green, pink, and red being the most common. Aurorae also take on many shapes: They can appear as diffuse patches of light, three-dimensional curtains, arcs, bands, bundles of rays, or as searchlights moving through the heavens. Your best bet for seeing an aurora is to look toward the north, although a large display can cover a significant fraction of the sky.

Aurorae occur in Earth's upper atmosphere and are triggered by the solar wind, a stream of charged atomic particles that flows from the Sun. When the solar wind encounters Earth many of the charged particles are trapped in the planet's magnetic field. These particles spiral along the magnetic field's lines of force until they crash into atoms and molecules in the upper atmosphere. These high-altitude atoms and molecules are excited into radiating light. Like a celestial neon sign they glow as the beautiful aurora, or northern lights.

### **A LIGHT ALONG THE ZODIAC**

There's another eerie glow you might see in the sky this month, this one in the west just after the glow of evening twilight fades from the sky. The zodiacal light, unlike the aurora, has nothing to do with Earth's atmosphere. It is produced by sunlight reflected off tiny dust grains in the plane of the solar system.

The zodiacal light is a faint, soft white glow in the shape of a cone that extends up from the western horizon. Look for it as soon as the western sky turns completely dark. The dust grains that cause the zodiacal light always surround us in space, but the light is easiest to see in the evening at this time of year because the ecliptic — which traces the plane of the solar system across our sky — now stands nearly upright in the west after sunset.

Although the northern lights are most often seen at northerly latitudes, the zodiacal light is easier to see the closer you are to the equator. As a Texan, I've seen the aurora only once, and that was while I was camping in Montana a few days after the 1979 total solar eclipse. They were the "searchlight" variety, green in color, and very much a surprise. On the other hand, I've seen the zodiacal light many times. From the Davis Mountains in West Texas, where the skies are very dark, the zodiacal light often appears quite noticeable on March evenings.

**SPECTACULAR AURORAL DISPLAYS** should occur more frequently at mid-northern latitudes this year as solar activity peaks. Photo by Forrest Baldwin.





## VENUS APPEARS FAR FROM THE SUN

Venus shines brilliantly at magnitude  $-4.5$  in the southeastern pre-dawn sky this month. The planet lies  $46^\circ$  west of the Sun on March 29/30, its greatest elongation for this morning apparition. Generally, Venus is at its best at greatest elongation because it is farthest from the Sun on the dome of Earth's sky. Yet Venus is actually *lower* in the southeast before dawn in late March than it is when the month begins.

This is a result of the ecliptic's shallow angle relative to the eastern horizon on late March mornings. The ecliptic is defined by the plane of Earth's orbit around the Sun, but the Moon and other planets (and the grains of dust that produce the zodiacal light) move nearly in this plane as well. Because the ecliptic makes such a shallow angle with the predawn eastern horizon at this time of year, Venus' great angular distance from the Sun does not translate into a great height above the horizon.

## MARCH'S PLANETS

The giant planet Jupiter lies high in the sky at sunset, shining brightly at magnitude  $-2.3$  from its location in the constellation Gemini. It is easily the brightest object in the evening sky, with the exception of the Moon.

Since December, when Earth passed between the Sun and Jupiter, we have been pulling ahead of the giant planet in our smaller and faster orbit around the Sun. As a result Jupiter is shifting closer to the imaginary line between Earth and the Sun. The Moon neatly illustrates this fact as it glides past Jupiter each month. Each time the Moon appears near Jupiter it appears less and less illuminated because it also lies closer to the Earth/Sun line and its lighted half is turned further away from our direction.

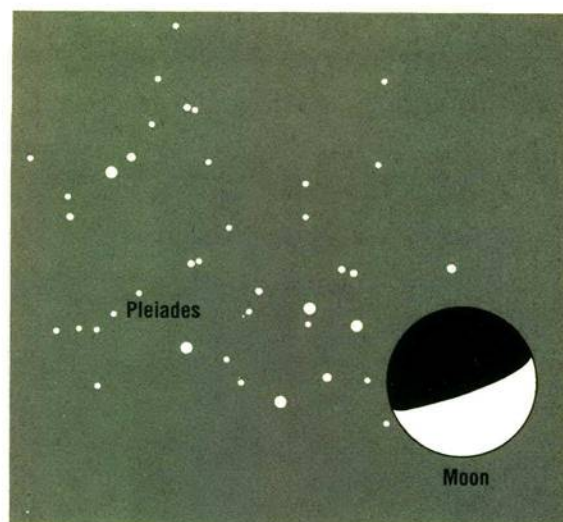
On March 4/5, for example, the Moon is slightly more than half illuminated when it appears  $5^\circ$  from Jupiter. On March 31 and April 1, when the Moon lies within  $10^\circ$  of the planet, it appears less than half-lit. And so it will go, with slimmer crescent Moons near the planet each month until Jupiter disappears from the evening sky in June.

Saturn and Mars lie  $1^\circ$  apart at the beginning of March. The two planets rise within ten minutes of each other on the 1st in the southeast before dawn. Saturn, at magnitude 0.6, is slightly brighter than 1.2-magnitude Mars. By month's end Saturn rises more than an hour before Mars and lies some  $20^\circ$  above and to the right of the other planet in the predawn sky.

Both planets are in Sagittarius at the beginning of March, but Mars moves into Capricornus after the first week of the month. Saturn, on the other hand, remains in Sagittarius for the rest of 1990.

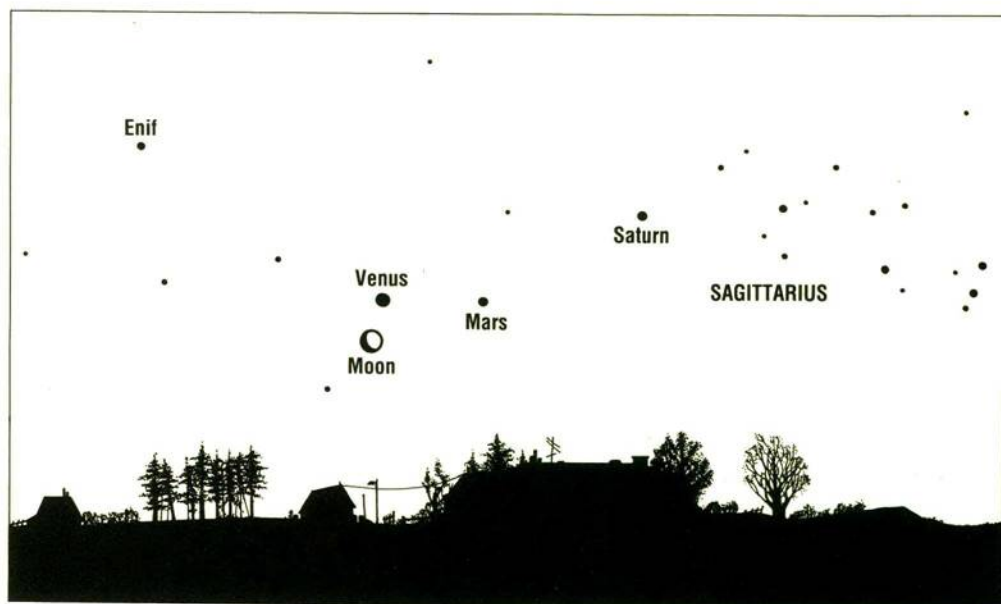
Venus also resides in the predawn sky, making for a trio of easily seen planets. The  $-4.5$ -magnitude planet reaches greatest western elongation — its greatest apparent distance from the Sun for this apparition — on March 29/30, although it is actually higher in the sky earlier in the month.

Watch the predawn sky throughout March as Venus, Sat-



**THE MOON AND PLEIADES** form a striking pair in binoculars on the evening of March 2.

**DAZZLING VENUS** lies just above the slender crescent Moon as twilight begins on the morning of March 23. Look toward the southeast to see the pair, with Mars and Saturn lying nearby.





urn, and Mars perform an interesting slow dance. As they did in February, the three planets form a triangle in the southeastern sky around mid-month. This time, however, Mars lies closest to the horizon. Another good time to look for the three planets is on March 21, 22, and 23 when the waning crescent Moon sweeps past them.

Innermost Mercury is in superior conjunction, more or less behind the Sun as seen from Earth, on March 19/20. It should become visible very late in March, a  $-1.3$ -magnitude point of light very low in the west shortly after sunset. Mercury will have its best evening apparition of the year in April.

## MARCH'S STARRY SKY

The Big Dipper is now prominent in the evening sky for observers all across the United States. The Dipper is an "asterism," a recognizable pattern of stars, in the much larger constellation Ursa Major, the Great Bear. Without a doubt it is the most recognizable star pattern in our sky.

From the southern United States the Big Dipper is not conspicuous on winter evenings because it lies close to or below the northern horizon. As spring approaches, however, it ascends in the northeast in the evening. The Big Dipper consists of seven fairly bright stars in a dipper pattern with four stars in the bowl and three in the handle.

The second star from the handle's end is really two stars, both of which are easy to see with the naked eye if you look carefully. The brighter of the two stars is 2nd-magnitude Mizar; its 4th-magnitude companion is called Alcor. At one time glimpsing Alcor with the naked eye was considered a good test of one's eyesight and the night's conditions. But Alcor is not difficult to see now, leading some observers to speculate that the star has brightened in recent centuries.

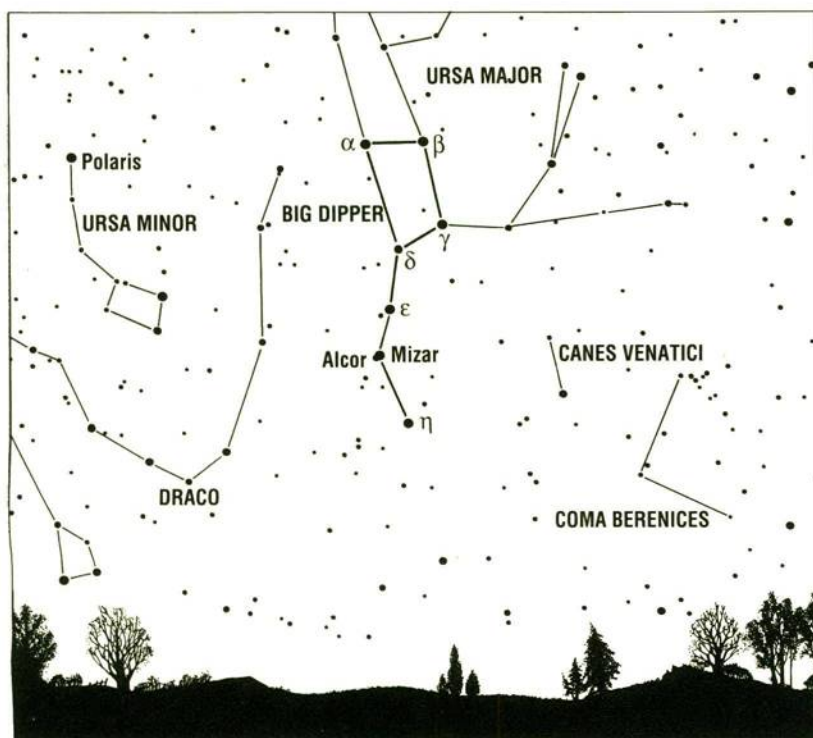
Despite their apparent association, Alcor and Mizar don't form a true binary system. In other words, they don't orbit around a common center of gravity. They are near each other in space, however, separated by at least a quarter of a light-year. Located approximately 75 light-

years from Earth, the two are members of the Ursa Major moving group, a loosely bound collection of stars that share the same motion in the Galaxy.

If you have binoculars you can see Mizar and Alcor display a strange effect sometimes called the "pendulum effect." Simply focus on the two stars with your binoculars then move the binoculars back and forth slightly, just fast enough that the stars remain visible as tiny dots of light. You'll see the faint star lag behind the brighter one as though the two are attached to the opposite ends of a string.

This effect is caused by the way our eyes perceive the light from the two stars. Since it takes longer for us to see the light from the fainter star, by the time we perceive its position the brighter star has already moved slightly ahead and the pair appears to swing like a pendulum.

**THE BIG DIPPER** rides high in the northeast on March evenings.





## **A VERY ACTIVE SUN**

It's always surprised me how seldom we observe the brightest object in the sky. The Sun is far more than the extinguisher of the night; it is also a rewarding target for observers with a telescope. The array of features you can see on the Sun are interesting from both a scientific and an aesthetic standpoint. And the features change from day to day so you always see something new. If you have never seriously observed the Sun before, now is the time. Solar astronomers predict that the Sun will reach its highest level of activity in nearly eleven years this March.

When you view the Sun through a telescope, the first features you'll see are sunspots. Sunspots are regions of the Sun's visible surface, or photosphere, that are considerably cooler than its surroundings. The average temperature of the photosphere is about 5700 kelvins, while the temperature of a typical sunspot is about 3800 K. If you could see sunspots against a dark sky they would appear a bright orange-red. Seen against the much hotter photosphere, however, they appear dark brown or black.

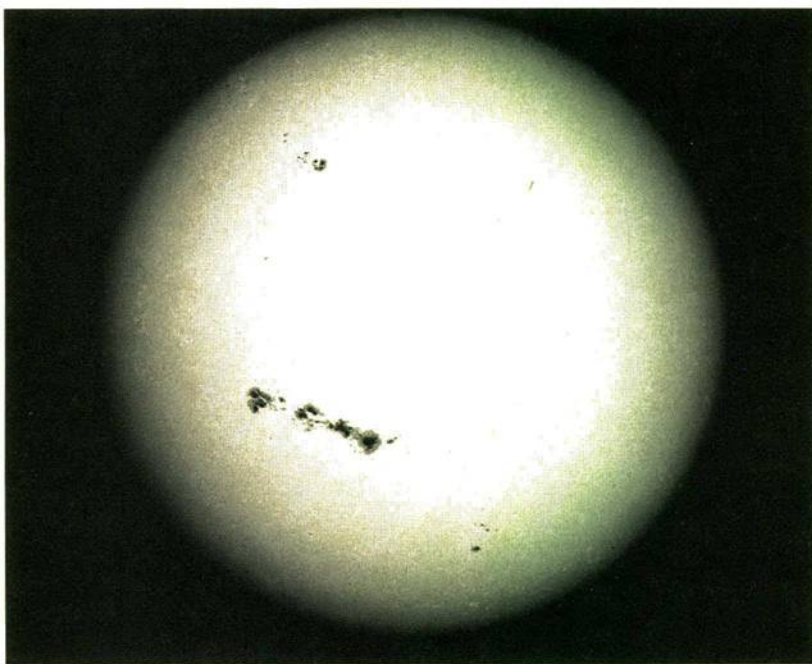
Most large sunspots exhibit both a dark central part called the umbra and a lighter, outer region called the penumbra. The umbra is the coolest area of the spot. The penumbra consists of numerous dark filaments radiating outward from the umbra.

As you observe individual sunspots from one day to the next, you'll notice that their umbras and penumbras change size and shape. In addition, you'll see the sunspots rotate around the Sun. Depending on their latitude, sunspots take anywhere from 27 to about 29 days to complete one rotation. Since some large spot groups survive more than one rotation, you might see a large group cross the face of the Sun, disappear at the Sun's eastern limb, then reappear at the western limb about 15 days later.

Although sunspots are the most obvious solar features, you might also want to look for some more subtle features. Most of the Sun's photosphere is covered with granules, small bright areas surrounded by dark, narrow lanes where hot gases from below the photosphere rise to the surface and release their energy. Although granules are subtle they are fairly easy to spot when the seeing is good by the mottled appearance they give to the photosphere.

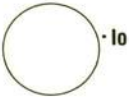
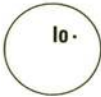
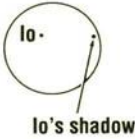
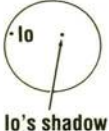
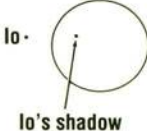
There are two final solar features you should try to observe: limb darkening and the bright white splotches called faculae. The Sun's edge, or limb, appears noticeably darker than the rest of the disk. This is because when we look at the center of the disk we see into deeper and hotter regions, which are consequently brighter than the higher layers we see at the edge.

Faculae are hot, bright regions of the photosphere that are easiest to see near the Sun's limb because they have higher contrast there than they do at the center of the disk. Faculae are usually associated with sunspots and often appear well before sunspots do and last for weeks



**A SLEW OF SUNSPOTS** will be visible to telescope owners in 1990 as solar activity reaches an historic high. Photo by Andrew W. Steinbrecher.



|                                                                                                          |                                                                                                          |                                                                                                          |
|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| March 5, 10:15 p.m.<br> | March 5, 11:00 p.m.<br> | March 5, 11:45 p.m.<br> |
| March 6, 12:30 a.m.<br> | March 6, 1:15 a.m.<br>  | March 6, 2:00 a.m.<br>  |

**WATCH IO AND ITS SHADOW** cross Jupiter's disk on the night of March 5/6. South is shown at top to match the view in a telescope; times are eastern standard. Other Jovian satellite phenomena can be seen at the times listed below.

| GALILEAN SATELLITE PHENOMENA |                    |      |
|------------------------------|--------------------|------|
| Date                         | Event              | Time |
| <b>IO</b>                    |                    |      |
| March 6                      | Transit begins     | 3:25 |
|                              | Shadow enters      | 4:39 |
|                              | Transit ends       | 5:38 |
|                              | Shadow leaves      | 6:53 |
| March 14                     | Occultation begins | 2:38 |
|                              | Eclipse ends       | 6:10 |
| March 29                     | Transit begins     | 3:37 |
|                              | Shadow enters      | 4:54 |
|                              | Transit ends       | 5:50 |
|                              | Shadow leaves      | 7:08 |
| <b>EUROPA</b>                |                    |      |
| March 10                     | Occultation begins | 2:55 |
|                              | Eclipse ends       | 8:12 |
| March 19                     | Transit begins     | 0:39 |
|                              | Shadow enters      | 3:13 |
|                              | Transit ends       | 3:18 |
|                              | Shadow leaves      | 5:54 |
| <b>GANYMEDE</b>              |                    |      |
| March 11                     | Transit begins     | 1:15 |
|                              | Transit ends       | 4:16 |
|                              | Shadow enters      | 6:21 |
|                              | Shadow leaves      | 9:28 |
| <b>CALLISTO</b>              |                    |      |
| March 24                     | Eclipse begins     | 2:24 |
|                              | Eclipse ends       | 5:21 |

Times are given in universal time. Subtract 5 hours to convert to EST, 6 hours for CST, 7 hours for MST, and 8 hours for PST.

after the sunspots disappear.

There are two safe ways to observe the Sun through a telescope: either with a good over-the-aperture solar filter or with the projection method. If you use an over-the-aperture filter, make sure *never* to look at the Sun through the telescope until you have firmly attached the filter. If a loose filter falls or is blown off suddenly, you'll fry your eye irreversibly. Also, always be sure to cover your finder scope when observing the Sun. Not only is it safer to cap

the finder, but you won't risk cooking the crosshairs.

You can also project an image of the Sun onto a blank white card or screen using a low-power eyepiece. However, this method runs the risk of damaging the coating or cement of the eyepiece lenses. This is because most modern eyepieces seem to place the field lens very close to the focal plane of the telescope, which exposes them to excessive heating when observing the Sun. If you decide to use the projection method, stop the aperture of your telescope down to 2 inches and use a cheap, long focal-length surplus eyepiece instead of a good eyepiece.

## JUPITER REACHES QUADRATURE

On March 23 Jupiter lies 90° east of the Sun, a configuration called quadrature. Jupiter's slight phase effect is most pronounced when the planet is at quadrature, and this month you should be able to see that the eastern limb of the planet is less well defined than the western limb.

But from an observing point of view, the most interesting effect of quadrature is seen in the phenomena of Jupiter's Galilean satellites. Jupiter's shadow lies as far to the east of the planet's disk at quadrature as it can. Thus, eclipses of the satellites and transits of the satellites' shadows occur when the satellites are farther from the Jovian disk, which makes the phenomena easier to follow.

Probably the best event this month occurs on the night of March 5/6 when Io crosses in front of Jupiter. At 3:25 universal time on the 6th (10:25 p.m. EST and 7:25 p.m. PST on the 5th) Io's disk begins traversing the Jovian disk. Then, at 4:39 UT (11:39 p.m. EST, 8:39 p.m. PST), Io's shadow first appears on Jupiter's disk. At 5:38 UT (12:38 a.m. EST on the 6th, 9:38 p.m. PST on the 5th) Io's transit ends, and at 6:53 UT (1:53 a.m. EST on the 6th, 10:53 p.m. PST on the 5th) the shadow leaves Jupiter's disk. The table lists the times of several other Galilean satellite events during March.

## THE MOON OCCULTS MARS AND THE PLEIADES

North American observers can watch the 6-day-old Moon occult the Pleiades star cluster (M45) on the evening of March 2. The Moon passes through the northern part of the Pleiades, but of the six brightest stars in the cluster only two, Taygeta and Maia, are occulted as seen from North America. Several of the fainter northern cluster members will be covered by the Moon's 40-percent lit crescent. Because the Moon is waxing the stars disappear on the dark limb of the Moon, which makes their disappearances much easier to see.

On March 22 the Moon occults Mars during daylight hours. Although daytime events take some effort to see, this event is rare



enough that you should seize the opportunity if you can. Observers throughout central and western North America, Mexico, and the central Pacific Ocean are in the path where the occultation is visible. (See the map at right for the areas of visibility.)

You should try to find the Red Planet about fifteen minutes before the occultation starts. On the West Coast you should search for Mars around 18:45 UT (10:45 a.m. PST). From central North America try to sight the planet around 19:00 UT (1:00 p.m. CST). Let the Moon guide you to 1.1-magnitude Mars and then follow the two objects closely as Mars disappears behind the Moon's bright limb.

## TELESCOPIC PLANETS

Mercury reaches superior conjunction on March 19/20 and is lost from view until the very end of the month. Look for it very low in the west just after sunset on the 31st. The -1.3-magnitude planet sports an 87-percent lit disk measuring 5.6" across.

Venus reaches its greatest elongation west of the Sun on March 29/30. Although Venus is quite low in the southeastern predawn sky its size and phase change fast enough that it is rewarding to watch. On the 1st the 31-percent-lit disk shines at magnitude -4.6 and measures 36" across. By the 31st the planet fades slightly, to magnitude -4.4, but its half-lit disk has shrunk 30 percent to 24.3" in diameter.

The main event for Mars this month is its daylight occultation by the Moon on March 22. Other than that, the Red Planet has little to recommend it observationally. Its 5.1"-diameter disk remains too small to reveal anything but a hint of the planet's intricate surface markings.

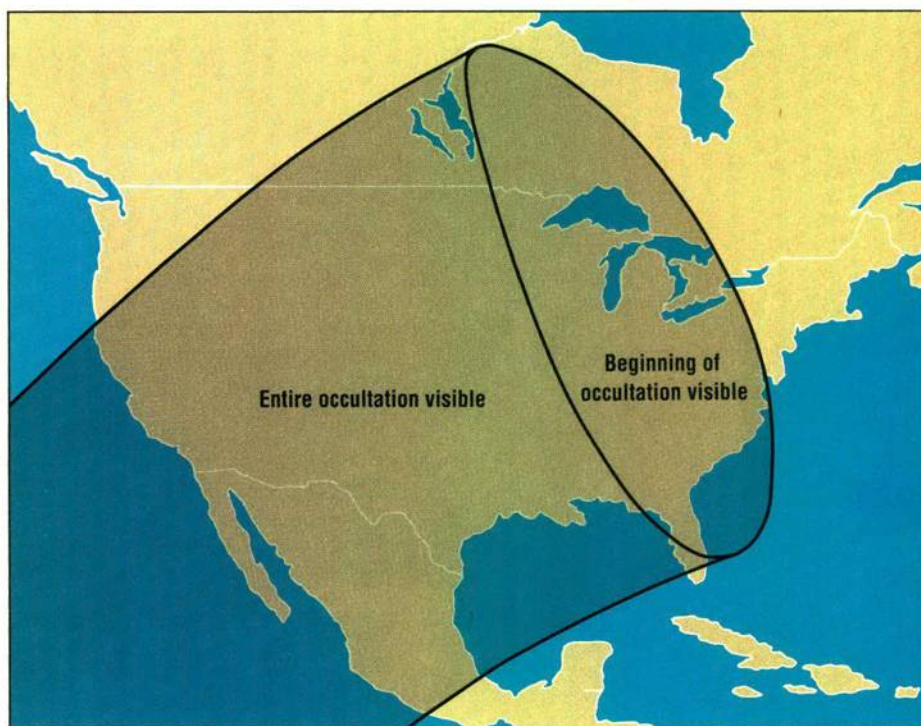
Saturn climbs higher in the morning sky this month, rising more than three hours before the Sun by month's end. The 0.6-magnitude ringed planet is thus high enough at the beginning of twilight for you to see its features and rings quite well. Saturn's pale yellow disk measures 16" across and is encircled by the planet's glorious ring system, which spans 36".

Uranus and Neptune remain in Sagittarius near much brighter Saturn. Uranus shines at magnitude 5.7 and presents a 3.6"-diameter, blue-green disk in the eyepiece. Neptune is an 8th-magnitude, blue-gray planet that measures 2.2" in diameter.

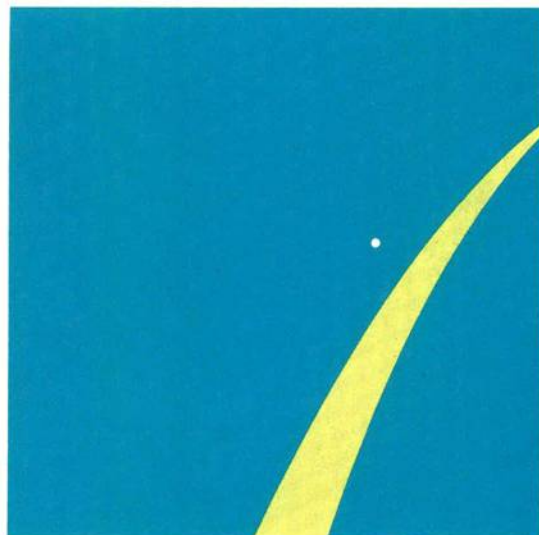
## COMETS FOR THE TELESCOPE

Although magnitude predictions for a comet making its first trip into the inner solar system are educated guesses at best, the recently discovered Comet Austin may reach 2nd-magnitude in late April and remain at 3rd-magnitude through most of May. In addition, the comet should be well placed in the morning sky during this time.

In March, however, Comet Austin is a very difficult object to see. The 5th-magnitude comet moves from Cetus into Pisces this month, where it lies 5° above the western horizon at the end of evening twilight. Next month, as the comet climbs into the morning sky, ASTRONOMY will present a complete observing guide for Comet Austin. □



**THE MOON OCCULTS MARS** during daylight on March 22. Observers in the darker shaded region can see Mars disappear and reappear before moonset, while those in the lighter shaded, oval region can only see Mars disappear before the Moon sets.





**Venus appears farthest from the Sun in March**

**Thalia is at opposition on March 27**

**Comet Tuttle-Giacobini-Kresak**

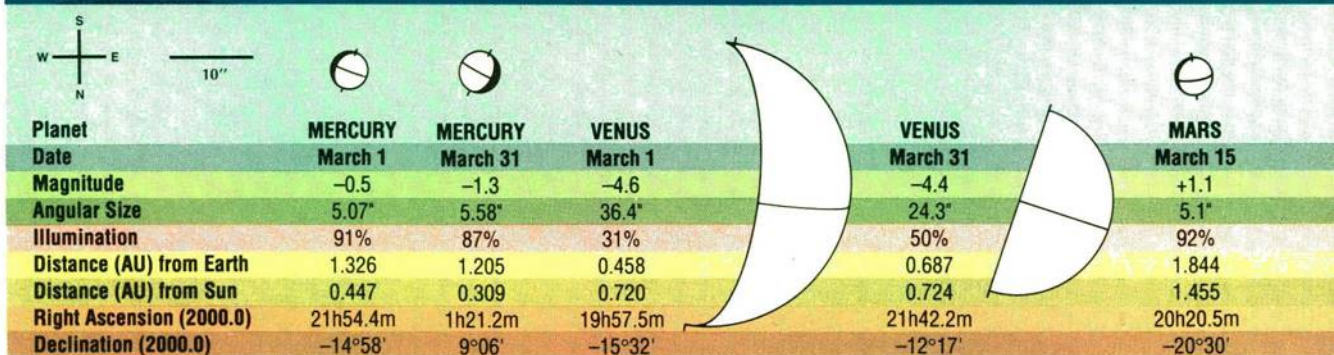
**The Moon occults Mars on March 22**

**The Moon passes 2° south of Saturn on March 21**

**Path of Moon**

**Morning Sky**

27 26 25 24 23 22 21 20 19 18 17 16 15 14 13



Dots display positions of Galilean satellites at 4 UT on date shown.

1  
2  
3  
4  
5  
6  
7  
8  
9

10  
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15  
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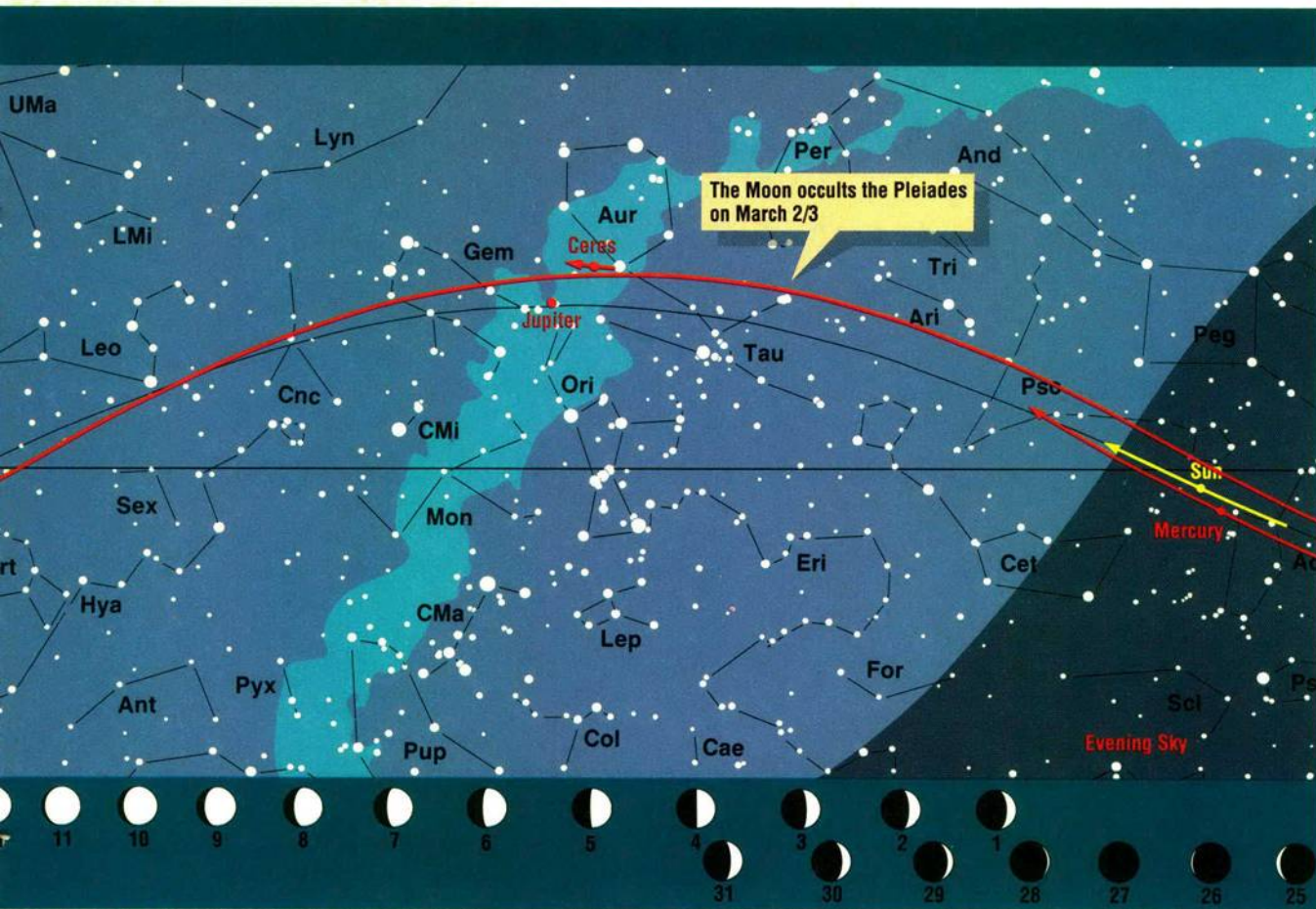
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31

Io  
Europa  
Jupiter  
Ganymede  
Callisto

Io  
Europa  
Jupiter  
Ganymede  
Callisto

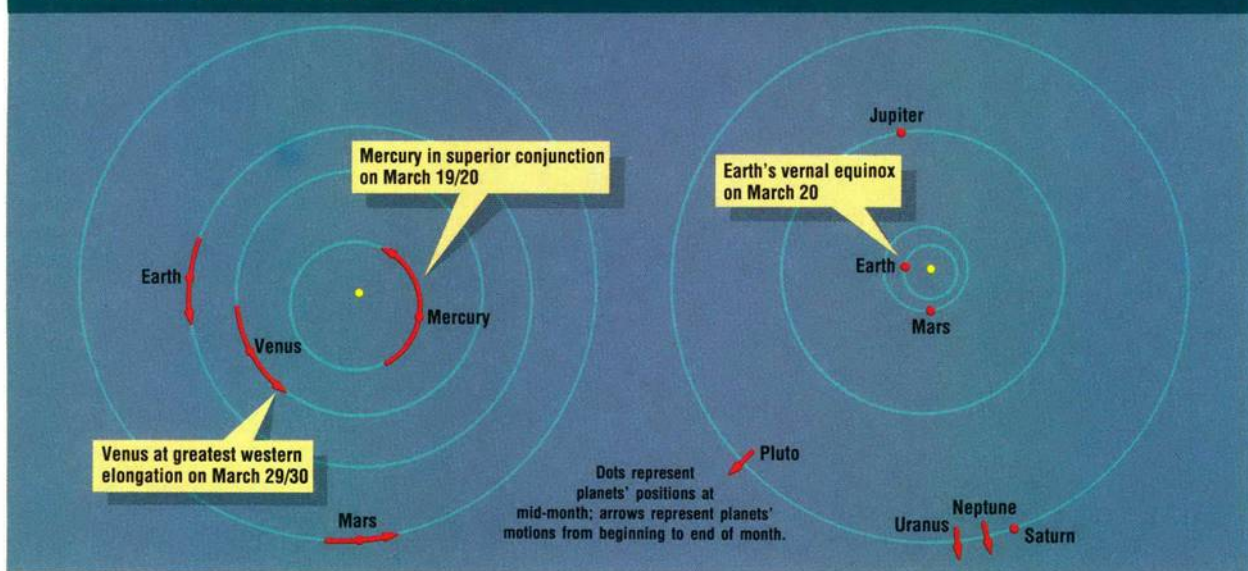
Europa  
Jupiter  
Io  
Ganymede  
Callisto





| JUPITER  |  | SATURN   |  | URANUS   | NEPTUNE  | PLUTO    |
|----------|--|----------|--|----------|----------|----------|
| March 15 |  | March 15 |  | March 15 | March 15 | March 15 |
| -2.3     |  | +0.6     |  | +5.7     | +8.0     | +13.7    |
| 39.7     |  | 15.8"    |  | 3.6"     | 2.2"     | 0.1"     |
| 99%      |  | 100%     |  | 100%     | 100%     | 100%     |
| 4.958    |  | 10.468   |  | 19.628   | 30.537   | 29.077   |
| 5.177    |  | 10.021   |  | 19.393   | 30.209   | 29.658   |
| 6h06.5m  |  | 19h41.0m |  | 18h40.8m | 19h02.2m | 15h18.7m |
| 23°29'   |  | -21°12'  |  | -23°24'  | -21°49'  | -1°54'   |

## The Planets in Their Orbits





# ASTRONOMY Tests

## the OR-840 Newtonian Telescope

A unique optical system and triple-axis mount distinguish this scope from ordinary Newtonians.

by Jeff Kanipe

**W**hen Optical Research Corporation of Appleton, Wisconsin, introduced their new line of commercial Newtonian reflectors with words like "unique" and "innovative," we were inter-

ested. Their telescopes feature fast focal ratios for low-power deep-sky observing but also employ a unique optical system that allows high-resolution planetary and double-star work. In addition, a fixed-height eye-

piece provides comfortable viewing no matter where the telescope points in the sky.

We wanted to know if these design features added up to a better telescope. To find out, we borrowed their 8-inch f/5 model, the OR-840 (they also offer 6- and 10-inch models), and observed with it for a week. We also tested the optics on an artificial star.

One glance at the white tube perched off-center on its gangly looking pier told us that this instrument is quite different in appearance from most Newtonian systems. But the optical design is also different. Optical Research has added an achromatic relay lens called the positive transfer element, or PTE, in an extendable eyepiece tube. The PTE's job is to transfer the image from the telescope's primary focus (which, unlike an ordinary Newtonian, is located *inside* the tube) to the eyepiece. By moving the eyepiece tube in and out, you can "zoom" through different magnifications. By using the 40mm Kellner or the 12mm Konig supplied with the OR-840 and two different lengths of eyepiece tubing, a continuous range of magnifications — from 50x to 675x — is possible. Each eyepiece tube is etched with two lines that indicate different magnifications.

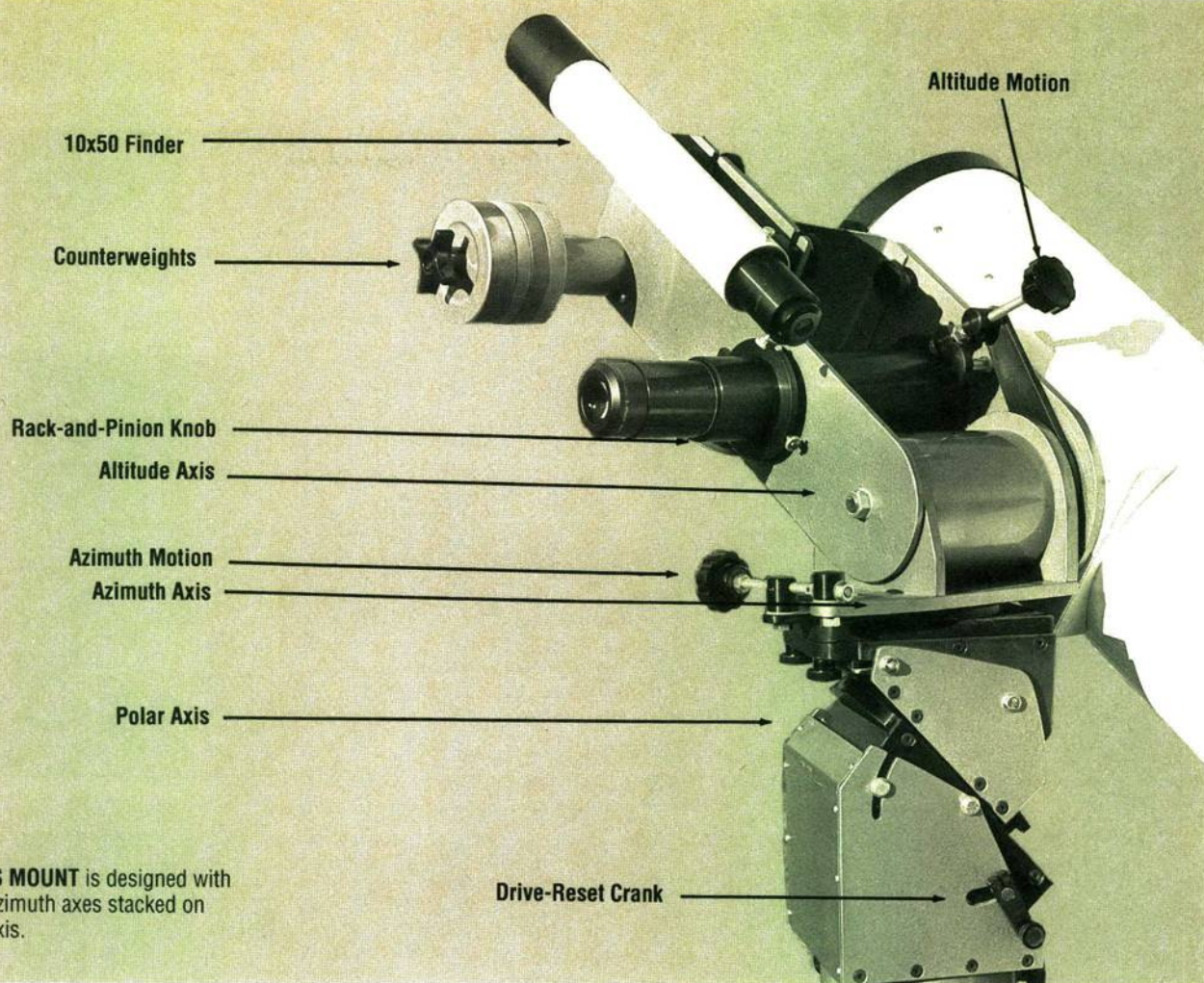
### Making a Better Newtonian

The inspiration behind the OR-840's unique design centers around a problem inherent to all reflecting telescopes, including Schmidt-Cassegrains; diffraction effects. Light passing down the telescope tube must pass around the secondary mirror and its support, which of necessity is positioned in the light path. These structures cause stars to ex-



**THE OR-840** features innovative ideas in a classic Newtonian design.





**THE TRIPLE-AXIS MOUNT** is designed with the altitude and azimuth axes stacked on top of the polar axis.

hibit thin projections, or diffraction spikes, that reduce contrast on planets and obscure faint companions in double-star systems.

To minimize diffraction, telescope builders use the smallest secondary mirrors they can and support them with thin, lightweight structures. Smaller secondaries are possible in reflectors with long focal lengths because the light cone from the primary mirror converges slowly. This means the secondary can lie farther up the tube where the cone has a smaller diameter. But the light cone in short focal-length reflectors converges quickly, thus a larger secondary mirror must be used to handle the greater diameter light cone.

The PTE, however, allows the focus of the OR-840 to lie inside the tube, where the light cone has a smaller diameter. Therefore, a 1.3-inch diagonal is all that's needed to receive the total light from the primary. The central obstruction amounts to only 12 percent of the diameter and 2.4 percent of the area of the primary.

In addition, the secondary is supported on a single curved secondary

holder, rather than a traditional four-vane "spider." This reduces diffraction by making the images appear less "spikey" (although this advantage is won with a slight loss of contrast).

#### Setting Up

The mount is a triple-axis platform — altitude, azimuth, and polar — equipped with manual slow-motion controls. The altazimuth section sits on top of the polar axis, on which a sector gear provides an hour's worth of tracking. At the end of the hour you must rewind the drive using the hand crank, which takes a few seconds. The polar axis can be set for latitudes ranging from 25° to 60° north.

The aluminum telescope pier stands 46 inches high. There are three pedestal legs and each has a leveling adjustment bolt. The drive-plug receptacle is conveniently located at the base of the pier and is supplied with an adapter for three-pronged plugs. The total weight of the telescope with counterweights is 85 pounds.

The manual claims one person can set up the OR-840 in ten min-

utes, which is about right. The mount itself is no problem. It is fairly light and is easily secured to the pier with three knurled knobs. Attaching the telescope tube to the mount can be tricky, however, especially in a low-light setting. You begin by swinging the mount to its vertical position (so that the counterweight stud is at its highest point). Then you heft the tube (about 16 pounds) onto the extension of the focuser on the mount and hold the tube against the mounting plate. While you're doing this you must screw in one of the four knobs without losing your grip on the tube.

After the tube is attached you slide the counterweights on the threaded stud and secure them with a knurled knob. The manual clearly warns the user to always attach the counterweights *after* the telescope is mounted and remove them *before* dismounting the tube. To do otherwise is courting disaster: From their vertical position, the counterweights could swing down suddenly and smack into the mount or, worse yet, strike your arm or head.

The 10x50 finder scope slides into



two slots above the eyepiece and is secured with two plastic knobs. One of the knobs is actually a double knob, which is used for horizontal centering. Vertical centering is adjusted by turning a thumbscrew under the front of the finder. Slipping the PTE into the rack-and-pinion focusing mount and inserting an eye-

piece completes the set up.

#### Handling

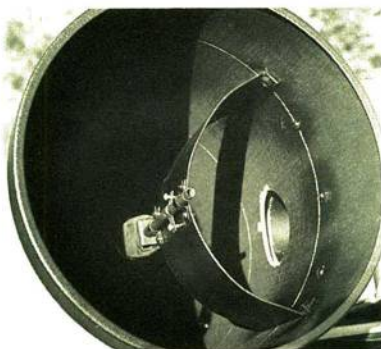
Our first night of handling this instrument was an awkward experience. Normally, you instinctively "nudge" an equatorial or altazimuth telescope while viewing through it in order to scan or keep an object centered. But even though the OR-840

moves in simple altazimuth directions, the telescope's unusual orientation on its mount combined with the pier's position between the observer and the tube make handling this instrument a not-so-straight-forward business at first.

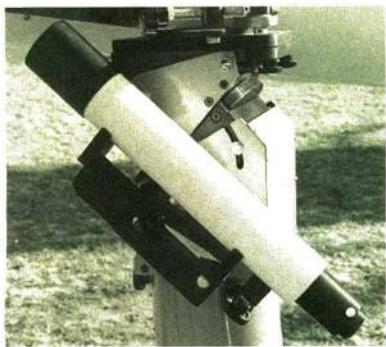
We found that the best way to maneuver the scope is to use the coun-



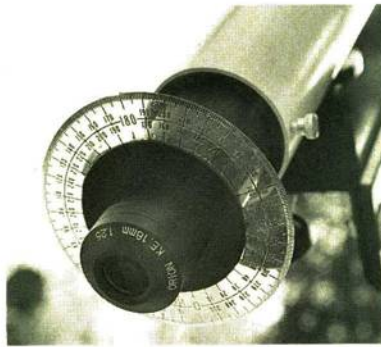
**THE POSITIVE TRANSFER ELEMENT** slips into the focus tube.



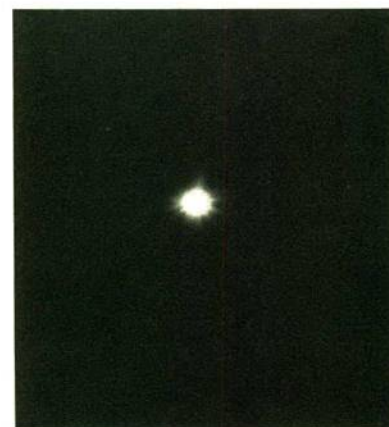
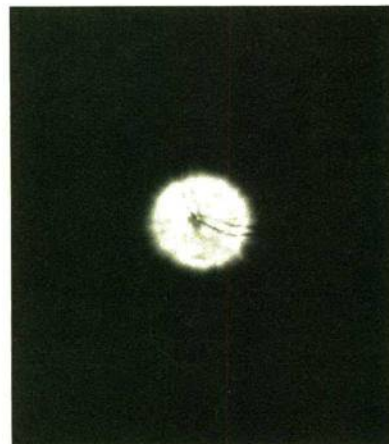
**A SMALL SECONDARY** and its curved support minimize diffraction.



**THE FINDER SCOPE** also serves as a polar-alignment scope.



**THE PROTRACTOR EYEPIECE** pinpoints the celestial pole's position angle.



**NO MIRROR DEFECTS** were found when Arcturus was viewed outside, at, and inside focus. The curved object is the secondary support profile.



terweight stud as a handle, with just a little push on the back end of the scope when pivoting in azimuth toward the observer. Fortunately, the slow-motion controls are within easy reach and are smooth enough to track an object once it's been found.

The fixed eyepiece height is a mixed blessing. On the one hand, the observer isn't forced to contort his or her body to accommodate the eyepiece; it's always in the same height range (five to five and a half feet) and parallel to the ground. But as convenient as this is, the tall pier, which makes this arrangement possible, produces a decrease in stability. Although the legs are broad and wooden inserts have been placed at the top and bottom of the pier to absorb vibration, the mount we tested is still too shaky. Light raps on the tube dampen out in an average of 5 seconds.

Optical Research has informed us, however, that they have increased the size of the pedestal legs. They are now 2 inches longer (16 inches) and 2 inches higher (12¼ inches). Since we haven't evaluated the new pier and pedestal, we can't comment on whether these changes have improved stability or not.

#### Polar-Axis Adjustment

The 10x50 finder scope doubles as a polar-alignment scope. After orienting and leveling the pier you attach the polar-alignment bracket to the pier with the alignment knob. Place the finder scope in the bracket's V-shaped cradles and secure it with the finder scope's middle bolt through a hole in the bracket. Next insert the 18mm protractor eyepiece in the finder and align with the dots for proper protractor orientation. Adjust the mount until Polaris lies at the edge of the field stop adjacent to the appropriate degree reading on the eyepiece protractor. The reading is simply the position angle of the celestial pole from Polaris at 9 p.m. standard time on different dates. For example, the position angle of the celestial pole on December 7 is 180° (i.e., directly "below" Polaris), while on June 7 it is 0°, (directly "above" Polaris). Correct position angles are provided in the telescope manual as are instructions on how to calculate the position angle for other dates.

#### Performance

Optical performance was judged on four separate nights to average out local seeing problems. A well-collimated 8-inch f/6 Newtonian reflector with no significant optical flaws was used as our "control" telescope. We first looked at the OR-840 mirror using a Ronchi screen

## The OR-840

An 8-inch f/5 Newtonian reflector employing a positive transfer element to relay the image from the prime focus of the telescope to the eyepiece. Standard features include a triple-axis mount with 60 minutes of tracking time, 10x50 finder scope, University Optics 40mm Kellner and 12mm König eyepieces, Telescopic 1/20th-wave primary mirror, Telescopic 1.30" minor-axis secondary mirror, polar-alignment bracket, 18mm polar-alignment eyepiece, collimating system, 2" rack-and-pinion focuser with 2" to 1.25" adapter, accessory case, and dust covers. Options available.

**Manufacturer:** Optical Research Corporation, 3009 East Forest, Appleton, WI 54915; (414) 734-5006.

**List Price:** \$2,195 for the OR-840; \$2,995 for the 10-inch OR-1050. (Call for price of the 6-inch model.)

**Pros:** Minimal diffraction, crisp images, eyepiece at comfortable observing height, smooth tracking system, variable magnification with one eyepiece.

**Cons:** Shaky pier, awkward tube attachment, rough rack-and-pinion focuser.

**Summary:** A good telescope for backyard observers who enjoy both deep-sky and planetary observing and short-exposure astrophotography. Because the eyepiece is relatively fixed, the OR-840 would make an effective telescope for public viewing sessions.



and detected no mirror stress or figure problems. Star testing the optics revealed that the brightest star and planet images displayed insignificant amounts of color fringing. Defocused 1st- and 2nd-magnitude stars showed no astigmatism, and the Airy disks displayed bright, circular inner diffraction rings both inside and outside of focus.

Testing on nights of good seeing gave us the opportunity to really appraise the telescope's optical performance. Focused star images at the center of the field of view indeed appeared more pointlike in the OR-840 than in our control 8-inch telescope, but they displayed some image flare at the edge of the field in the 2-inch eyepiece.

We found that the OR-840 outperformed our control 8-inch when it came to views of Jupiter. The north equatorial belt and other atmospheric features were contrasty and the disk displayed a clean, distinct edge. The telescope also provided steady views of Epsilon Lyrae, the Double-Double, which showed a thin, dark gap between each double component. Our control 8-inch also split the Double-Double, but not as cleanly as the OR-840. Views of

open star clusters and the Orion Nebula appeared virtually the same in both scopes.

Finally, we brought the telescope to the office and, after carefully collimating it, looked at an artificial star. As with the real star images, we saw a clean, circular Airy disk and no astigmatism. We noticed chromatic aberration from the PTE, however, in the form of a red blur around the star image. Optically, we give this telescope an A minus.

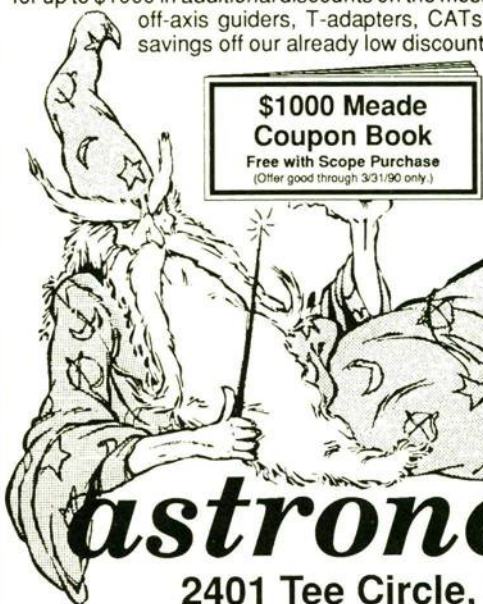
It was convenient and easy to zoom into different magnifications using the PTE. Ironically, fine focusing was more difficult because the rack-and-pinion focuser is not very smooth. The cog and tooth gear tend to bind, and when we racked out the focuser to the end of the toothed track, the cog would catch on the limit screw.

Aside from the shaky pier, awkward set up, and rough rack-and-pinion focuser, we think the OR-840 can deservedly be called innovative. If the optical performance of the telescope we tested is representative, the OR-840 exemplifies an effective synthesis of short focal-length image brightness with long focal-length image quality. □



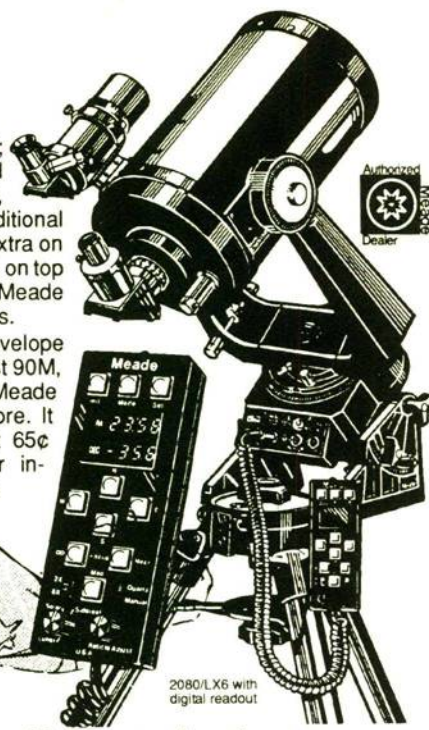
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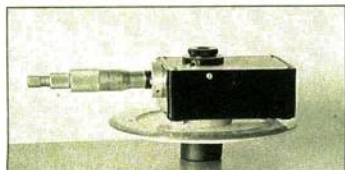


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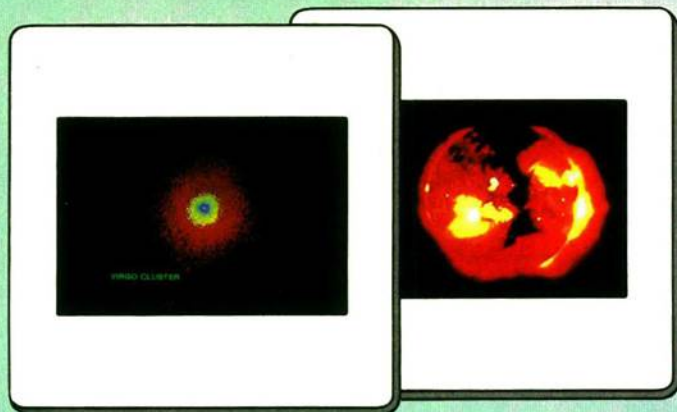
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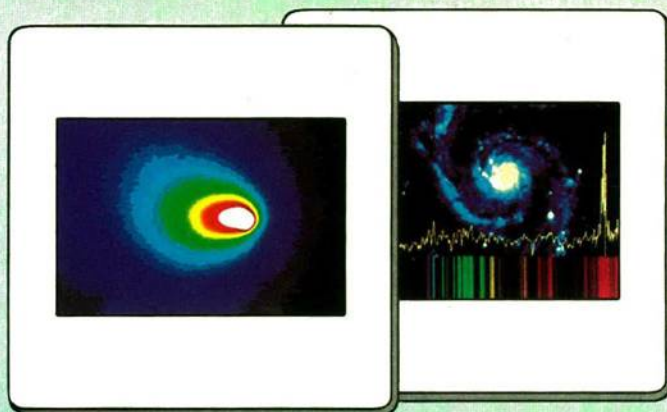
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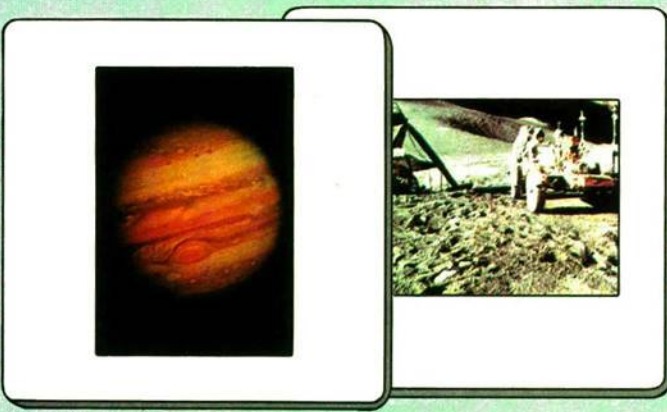
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# How to Turn Astro-Negatives into Great Astro-Slides

It's easy to convert high-speed negatives into breathtaking color slides you can show to all your friends.

by Robert Bunge

If you're an astrophotographer, you've probably encountered a certain irritating problem. Prints may be a great way to show a friend or two what the Orion Nebula looks like, but if you've ever tried to talk astrophotography to a dozen people or more by passing around some prints, you know how frustrating the experience is. There you stand, jabbering till you're blue in the face, while everyone huddles around your prints and no one really hears what you say. Worse yet, those precious prints, which cost time and money, come back dog-eared and fingermarked.

The core of the problem is that while the best high-speed films on the market produce color *prints*, what you need to show off your work is a big tray of color *slides*. So how do you get from one to the other? Easy! The answer is a special Kodak film called Vericolor 5072 that was de-

signed to convert negatives into positives.

Photo professionals call 5072 an unmasked color negative film, which means it is a normal color negative film minus the distinctive orange-tinted "mask" that ordinary color negative films need for printing on paper. The procedure for making copies with 5072 is very simple: re-photograph your color negatives onto it and develop the film. The result is a positive color transparency.

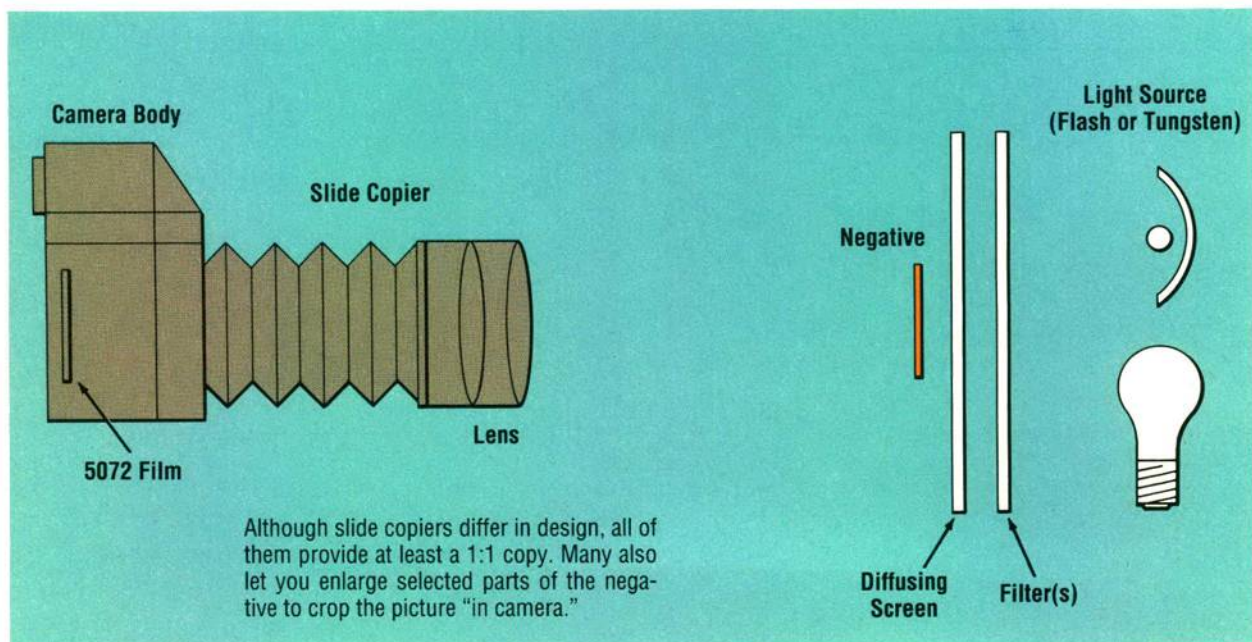
Vericolor 5072 is a great film to work with because the process of turning your negs into slides gives you nearly as much control over the final product as making a print, and it's easier to do since you don't need a darkroom. Another advantage is the convenience of getting 5072 processed. The film is processed in normal C-41 chemistry just like any standard color negative film, which means almost any one-hour photo-

lab can do it.

Modern C-41 machines are quick, too. Most process film in less than half an hour, so you can have an ice cream cone at that shop across the mall while you wait. Also, C-41 processing can be done at home without too much trouble if you are already equipped for doing black and white.

Vericolor 5072 is widely available as well. The larger camera stores in most cities normally carry it and any that don't can order it easily from Kodak. The film comes in both 36-exposure rolls (in standard cassettes) and 100-foot rolls that fit into bulk loaders.

In a 36-exposure roll, 5072 is called SO-279 and costs about \$4. A roll or two will let you try the process out, but in the long run it's much better to invest \$15 to \$20 in a bulk loader and get the 100-foot rolls. The long rolls cost about \$60







To turn that great Orion Nebula negative into a slide you can project, make a copy of it. Kodak's Vericolor 5072 is a negative film specially designed for transforming negatives into transparencies. Konica 3200 original (left) and 5072 slide by the author.

apiece and each yields about twenty 36-exposure rolls.

The big advantage in using 100-footers, aside from a small savings in price per roll, is emulsion uniformity. The problem with buying individual short rolls is that unless you buy several at once you run the risk of getting rolls coated with different emulsion batches. In a perfect world one batch of 5072 would be identical to every other, but in reality different batches often require different color filtration and exposure. This means that the time-and-filter combination you carefully work out for one roll may not transfer to the next. Another important consideration is

that you often need just a 10- or 15-exposure roll, which bulk loaders make easy.

What else do you need? The other big item is a slide copier. There are many different types on the market today. The easiest to use is one with a built-in close-up lens and flash. Simple lens-only copiers can work with either a small flash unit or a tungsten bulb as a light source. I use an old bellows unit and place a flash at the end facing the camera. This lets me use my normal 50mm lens, which I stop down to  $f/16$  to get sharp images at the edge of the frame.

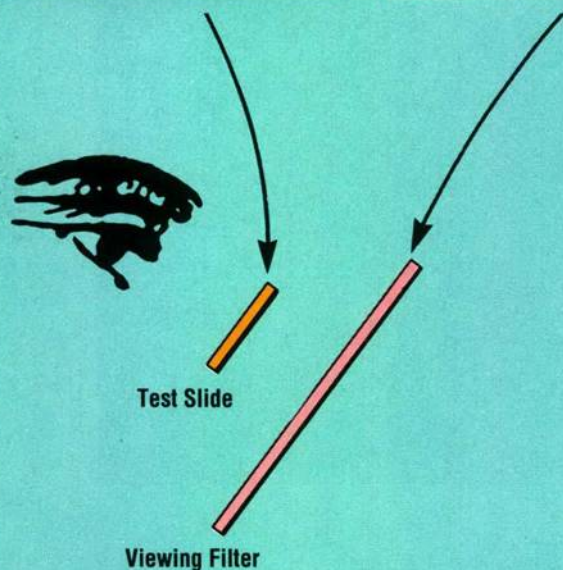
You need two other pieces of equipment: a set of CP color correc-

tion filters and a packet of color viewing filters. The CP filters come in sets costing about \$30 to \$35. You place them between the negative and the light source. The color viewing filters are used to gauge the amount of color correction needed to get a slide just right. These filters normally come as a kit with six pieces of cardboard, each holding three filters with different densities. Kodak's R-25 set costs about \$11 and comes with all the necessary instructions.

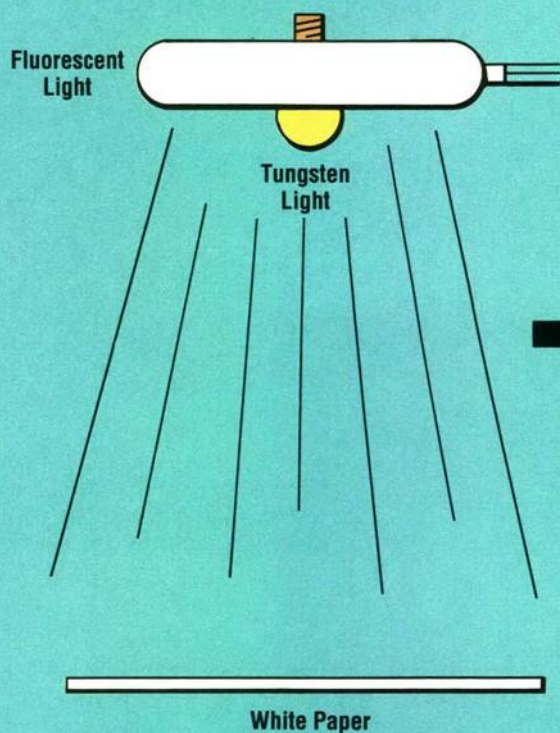
The first step in making a slide using 5072 is to choose a well-exposed negative. For your first try I recommend picking a negative that



## Judging Color the Easy Way



Start with a trial slide that has color problems (top left), such as this shot of the Omega Nebula. View the slide under the proper lighting conditions (above) with filters from Kodak's R-25 set (top right). When you find the right filter to correct the slide's color, follow the instructions on the filter mount.



is representative of one of your normal photos. In other words, choose a picture shot at your normal site, with your favorite film, using an exposure of average length.

Dust the negative carefully using a soft camel's hair brush or a squirt of canned air and place it in your copier. To keep things in order, it's easiest to orient the negative in the copier with the emulsion facing

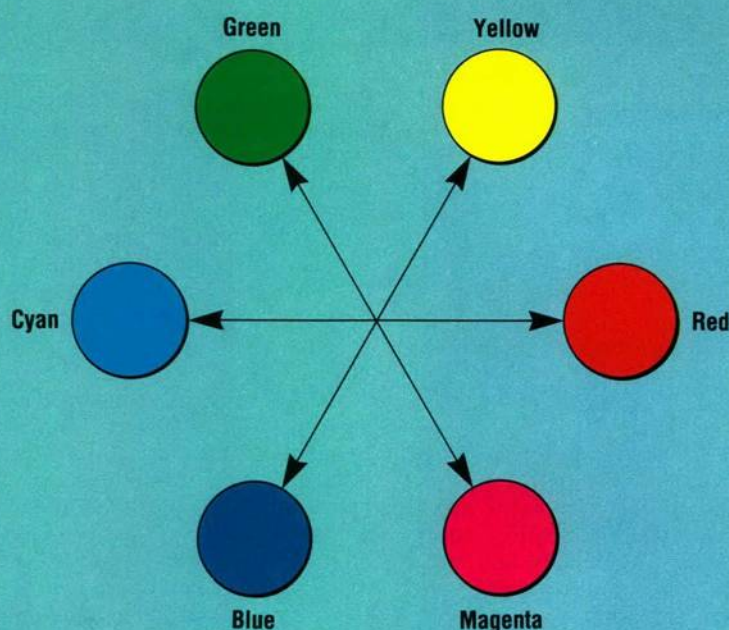
away from the camera. (If you can read the writing on the edge of the negative through the camera's viewfinder, you've got it right.) Keep in mind that most 35mm SLR cameras don't show 100 percent of the actual frame in the viewfinder.

The next step in slide making is choosing a trial filter pack. The color correction filter set comes with a series of three colors (yellow, magenta,

and cyan), each in a range of densities. The density is measured in units called Color Compensators or CCs for short. Each series should include densities of at least 2.5, 5, 10, 20, 30, 40, and 50 CCs for each of the three colors.

Although the filters can be stacked in various combinations to give an almost endless range of filtration, experience will soon show you which





Getting a slide with the proper color (above) involves learning the relationships diagrammed in the color wheel (top). Colors across from each other are complementary.

combinations are most useful. To start with, if you are using a flash as a light source, try a filter pack of 50 magenta and 50 yellow. If you're using tungsten light as a source, begin with 10 magenta and 10 yellow. These should put your first test exposures in the right color ballpark.

Load the camera with a roll of 5072. (Use a 10- or 15-exposure roll if you bulk-loaded the film.) With

the copier's aperture set to its widest opening, focus on the negative. You won't know how much exposure to use so you'll have to proceed by trial and error.

If the output of your flash is variable, it's best to stop the copier's lens all the way down (for sharpness). Make a series of exposures starting with the flash set at full power and cutting its power in half with each

succeeding frame. If the flash has a single fixed brightness, start with the lens stopped completely down and open up one stop with each frame. (Depending on the copier, this may introduce some slight unsharpness.)

If your light source is tungsten, you are not tied to any one exposure setting. Therefore, stop the lens all the way down and begin with an exposure of a quarter second. Double each succeeding exposure until you reach eight seconds. Be sure to record each frame's exposure and the filtration for the roll.

Now have the film processed. Explain to the clerk that the film is 5072 and that it needs to be processed in C-41 or compatible chemistry. A good photolab will know what 5072 is and will know how to proceed. Be sure to ask that the film not be cut into strips when developed. If they cut the film you may not be able to reconstruct the order in which you took your test shots. If you bulk-loaded the film, remember to ask them to return your film cassette.

After you get the film back, examine the images. The best method for viewing the test roll for density and color is by holding the film up to a smooth white background about three feet away. (See diagram at left.) Even though the image may appear too red or green or yellow or some other color, at this point concern yourself only with density. Pick the best-looking frame and check your notes to see what the exposure was. If one frame is too dark and the next is too light, then your base exposure will fall somewhere in between.

Once you find the frame with the right density, gauging color comes next. To judge color correctly, the white surface should be lit with a combination of both fluorescent and tungsten light. It's important to view with the combined lighting. If you used fluorescent light alone, you would judge the test frame's color in a way that would cause your final slide to come out too cool (green, blue, cyan). Likewise, using tungsten alone would skew it toward the warm colors (magenta, yellow, red). An easy way to combine the two types of lighting is to take the shade off a desk lamp in a room brightly lit with fluorescent lights and place the desk light a few feet in front of you. Try to achieve an even balance between tungsten and fluorescent light.

If the test frame appears way off in any one color, look at it through the viewing filters of the color that is



## How to Fix Color Imbalances

### If the color is too:

| Cyan                           | Blue     | Green    | Red                | Yellow | Magenta |
|--------------------------------|----------|----------|--------------------|--------|---------|
| <b>Change the filter pack:</b> |          |          |                    |        |         |
| Subtract                       | Subtract | Subtract | Add                | Add    | Add     |
| Magenta and Yellow             | Yellow   | Magenta  | Magenta and Yellow | Yellow | Magenta |

complementary to the frame's overall color cast. (The color wheel on page 71 shows which color this is.) Be careful! It's easy to confuse similar colors: magenta and red, for instance, or blue and cyan. Be sure to try several different viewing filters to pin down just which corrections are needed. To tell how much correction is called for, use the viewing filters' different densities.

Making slides with 5072 is much like making a color print. Read the instructions that come with the viewing filters and follow their directions and hints. While at first it's hard just to gauge what color needs correction, it becomes easier with experience. You soon learn that if the test frame looks pinkish, for example, it's really too magenta, not too red. Likewise, a light sky-blue tint may indicate the frame is too cyan, not too blue.

Never use more than two color filters in your filter pack at once. Using all three together just adds density without changing the color. Five CCs of yellow, magenta, and cyan used at once, for instance, simply produces a neutral gray.

Change the filter pack as required and prepare to shoot another test roll. Handle the filters carefully to avoid smudging them. (A pair of thin cotton gloves, available at any photo store, really helps.) Choose the best density from your first test roll as a starting point. For this new test series bracket the exposures one or two stops on either side of your base exposure using half-stop increments. Vericolor 5072 is quite sensitive: large changes in density result from small changes in exposure. If you end up with unused exposures on the roll after your tests try varying the filter pack in new ways or start the basic exposure series for a wholly new negative.

Here are a few hints. You'll find

that changes in the filter pack, especially changes in magenta, will affect the exposure, so be sure to bracket the exposures each time you vary the pack. Also, don't try to correct more than one color at a time. If you think the slide is simultaneously too red and too yellow, correct one color first.

The toughest and trickiest correction to make is when the frame appears both too warm and too cool — for example, too magenta and too blue. Typically the frame has a sickly looking pinkish blue that resembles the light from a high-pressure sodium lamp. When you get this kind of test back from the processor, you may be tempted to give up. Don't. The procedure for fixing it is the same as before: correct one color first and then the other.

Because your slides are intended to be projected, be sure to run at least some of the test frames through the projector you normally use. Apart from color, this also provides a good check for density. Very often a slide that appears too dark when viewed by eye will project well enough in a darkened room.

Besides making positive copies of negatives, 5072 has also been used by astrophotographers for years to enhance their photos. The film is inherently contrasty; it tends to brighten colors and increase the difference between light and dark areas. Some astrophotographers copy their negatives onto 5072 then recopy the resulting positive back onto an ordinary fine-grain negative film. This "internegative" is then recopied onto 5072 a second time. The result is a slide with greatly enhanced contrast and detail.

But anything this good always exacts a price. Like any contrasty film, 5072 has a narrow exposure latitude; it is also pretty picky about how it's processed. Always take your

rolls to the same photolab because each lab runs its C-41 machine a little differently. (The change will be even more apparent between two labs that use different brands of chemicals, say Kodak and Fuji.) An exposure and filter pack that delivers good results when the roll is processed at one lab may not work at another lab. It's even possible, if you become a regular user of 5072, to tell when your lab's processor starts to have problems just by monitoring the changes in color and/or density of your slides.

This sensitivity also means that if you process 5072 at home, you need to be careful about using fresh chemicals and maintaining proper temperatures. Store the unexposed film in a refrigerator (but don't freeze it). This increases the film's shelf life and maintains its color balance so you won't have to be changing the filter pack as the film ages.

The high contrast of 5072 means that different brands of color negative films (Kodak, Fuji, and Konica, for instance) will require different filter packs. If you shoot more than one brand of film, be sure to keep very detailed records. That way you can start off with a basically correct filter pack for each type of film. In some cases, however, even the same type of film can require a markedly different filter pack. If, for example, you sometimes shoot astrophotos from a light-polluted site, the background sky fog will require a different filter pack than that needed for photos taken from a dark sky site. The same holds true if you photograph a comet during twilight or use a light-pollution filter during the exposure.

Showing your astrophotos in slide form protects them from mishandling and damage. It also lets many people see them at once. But maybe the most important reason for using 5072 is one of the least obvious: you gain control over the slide's final appearance without the expense or mess of a darkroom and its chemicals. Slide making with Vericolor 5072 gives you complete control over the density, color, cropping, and final appearance of the finished product. Now what astrophotographer could ask for more than that? □

*Robert Bunge is an experienced amateur astronomer and astrophotographer from Columbus, Ohio. His last article for ASTRONOMY was "Great Astrophotos in Less Than an Hour" (August 1989).*



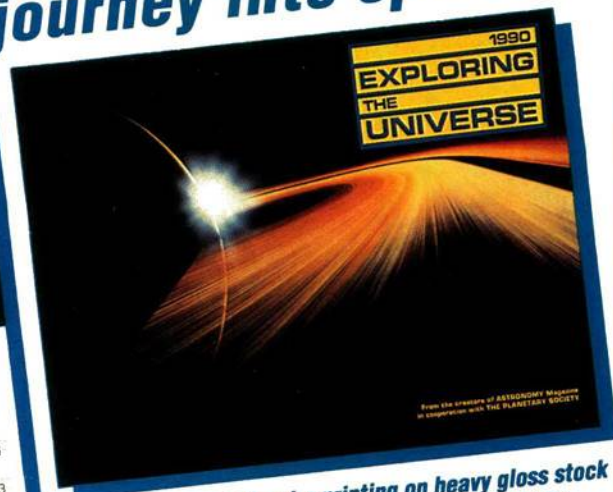
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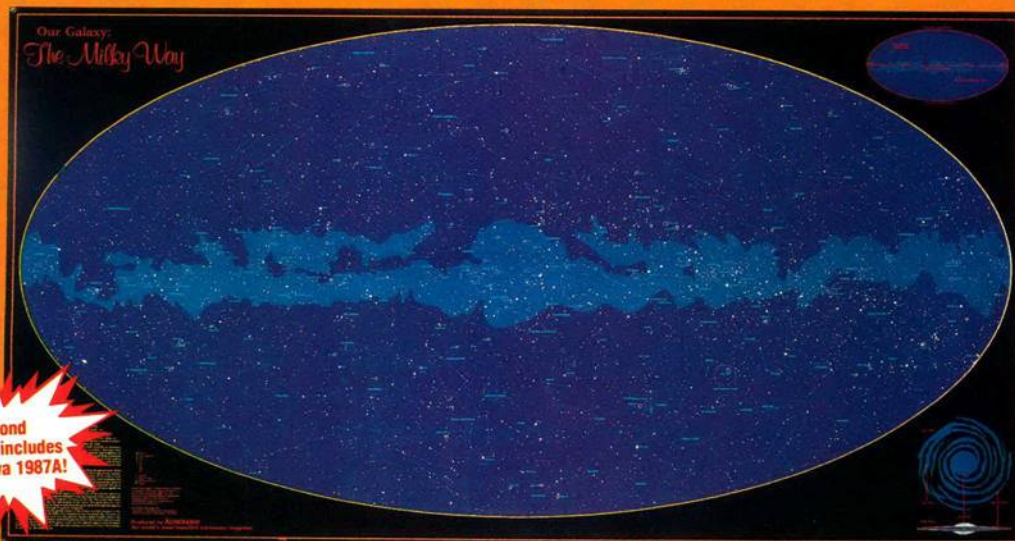


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# EXPLORE THE SOUTHERN SKY

Rich with nebulae, clusters, and the dazzling Magellanic Clouds, this region contains some of the most spectacular objects in the heavens.

by Gregg D. Thompson

**W**here can you find the finest globulars, the brightest and most detailed galaxies, the richest open clusters, the brightest and most impressive nebulae, and the largest and darkest dark nebulae? In the southern sky.

From about 30° south latitude the center of our Galaxy passes directly overhead, providing exquisite views of all types of galactic objects. The rich Centaurus arm of the Galaxy lies in the southern sky and offers spectacular views of open clusters, the Eta Carinae Nebula, and the dusty dark nebula called the Coal Sack. The southern sky also holds the biggest and brightest globular clusters and the Magellanic Clouds, our galaxy's satellites. Whether you visit the Southern Hemisphere on a vacation or observe the southern sky year round, there's an awful lot to see.

The best object in the southern sky is the **Large Magellanic Cloud**, the largest satellite galaxy to the Milky Way. Near the center of the LMC lies the **Tarantula Nebula** (NGC 2070), the brightest object in the

LMC. This object is completely unlike anything visible in the northern sky: A 12.5-inch scope casually aimed near its center shows a bright, complex structure with tentacles of nebulosity that are both bright and faint and narrow and broad.

As the field drifts, you see scores of other gaseous nebulae, open star clusters, and globulars. One region that can be glimpsed with a keen, unaided eye is the group of nebulae designated **NGC 1760-9**, a large cloud containing several bright star clusters in three basic clumps. Another fascinating nebula is **NGC 2032-5**, the Seagull Nebula. This object is shaped like a seagull about to dive.

Unfortunately, the Milky Way's other satellite galaxy, the **Small Magellanic Cloud**, is often overlooked, although it too contains unusual clusters and nebulae. The SMC's answer to the Tarantula Nebula is the bright nebula **NGC 346**. NGC 346 can be glimpsed with the naked eye under perfect conditions. In my 12.5-inch scope at high power the nebula fills over half of the field of view. Nearby lies **NGC 371**, a bright star cluster best viewed with a nebular filter, which shows an almost perfectly circular nebulosity enveloping the cluster.

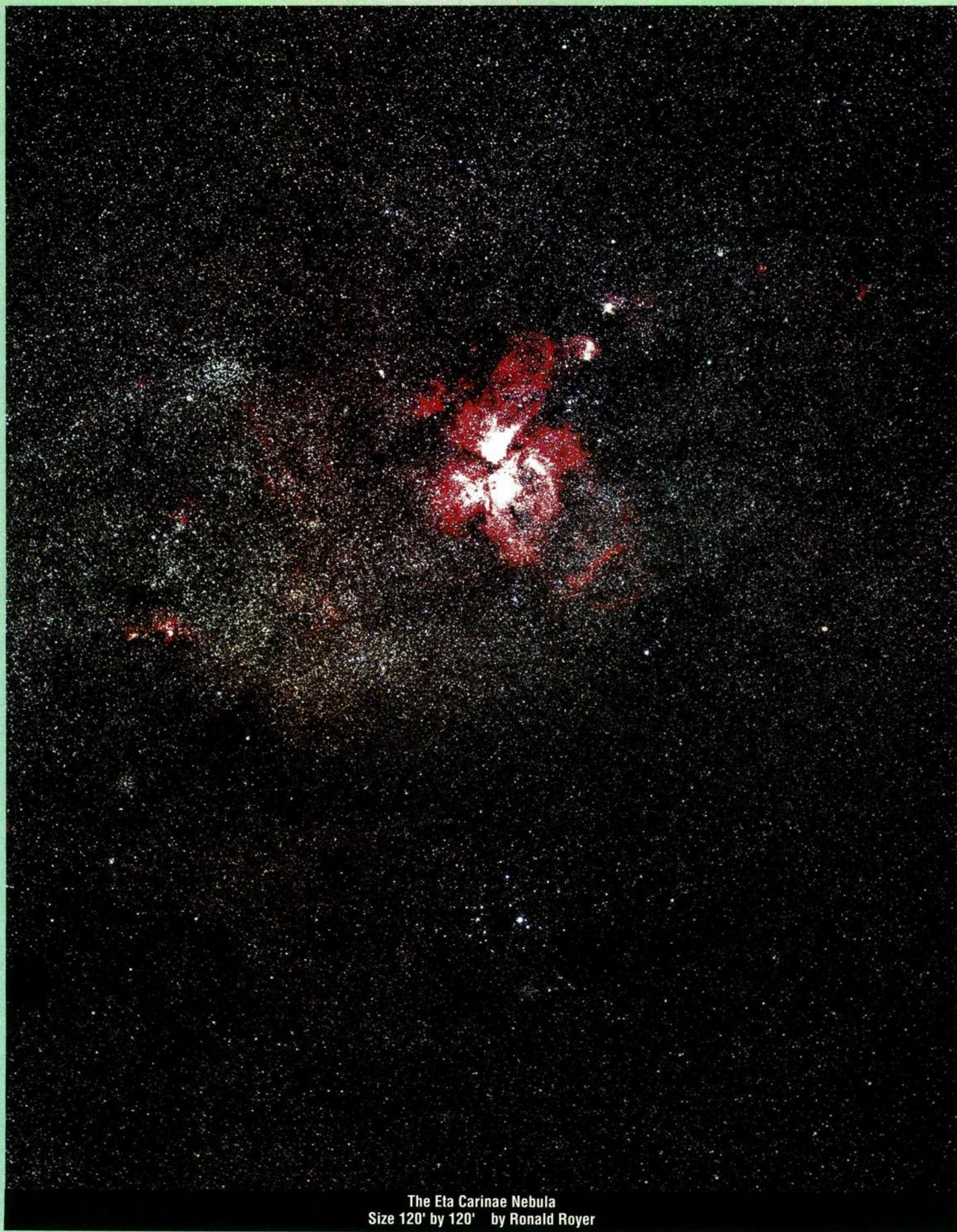
The beautiful globular cluster **NGC 362** lies near the tail of the Small Magellanic Cloud. NGC 362 appears so rich in a 12-inch or larger scope that it confounds those who want to sketch it. Thousands of glowing points crowd inside a high-power field of view. Although NGC 362 is smaller and dimmer than Omega Centauri, its center is far more concentrated. Nearby **47 Tucanae** (NGC 104), a globular belonging to the Milky Way, is one of the two finest globular clusters in the sky. The outer stars in this cluster appear much fainter than the ones in close to the center. The core of 47 Tucanae is so jammed with stars that it appears like one globular laid directly upon another. The cluster's core stars are strongly yellow in color.

The most beautiful cluster in the southern sky is the elliptically shaped **Omega Centauri** (NGC 5139). This object is easily visible with the naked eye as a fuzzy "star." In binoculars it is comet-like and was often confused with Comet Halley when the comet passed near it in April 1986. Backyard telescopes resolve thousands of Omega's estimated one million stars. Near its broad central region are three small, dark oval patches silhouetted against the stardust background. The two most prominent form owl-like "eyes."



The Southern Milky Way in Crux  
by Chris Floyd





The Eta Carinae Nebula  
Size 120' by 120' by Ronald Royer





**Peculiar Galaxy NGC 5128**  
**Mag. 7.0 Size 18.2' by 14.5' by Jack Marling**

This feature has no physical significance, however; it is formed by chance arrangements of bright stars.

Several other southern globulars are worth a look. The impressive globular **NGC 6397** lies in the constellation Ara. Although not the largest globular in this constellation, NGC 6397 is rich, bright, and condensed. **NGC 6752** in Pavo lies beside an 8th-magnitude star. This cluster can be resolved into many members in a small telescope, but its prominent background glow is evidence that countless faint stars remain unresolved. **NGC 4833** in Musca has two distinctive areas without bright stars, making it appear that a "V"-shaped incision has been cut into the globular's core. **NGC 5286** lies beside the naked-eye star M Centauri. **NGC 2808** in Carina is rich and compressed to a brilliant core that looks like a more distant version of 47 Tucanae.

One of the most peculiar objects in the southern sky is the spherical galaxy **NGC 5128** (Centaurus A). This object appears like a large ball of light bisected by a prominent dust band. In telescopes larger than 12.5 inches in aperture, the double nature of the dust lane can easily be seen. Radio telescopes pointed at Centaurus A "hear" a rumble that astronomers think originates from a black hole at its core.

Another beautiful sight that lies nearby is the edge-on galaxy **NGC 4945**. This object is faintly visible in binoculars; in an 8-inch telescope it extends from one side of the field to the other, spanning nearly 30'. Pavo's **NGC 6744** is a huge face-on spiral. This galaxy's arms are too faint to be easily recognizable in small telescopes, but an 18-inch or 20-inch scope does the trick.



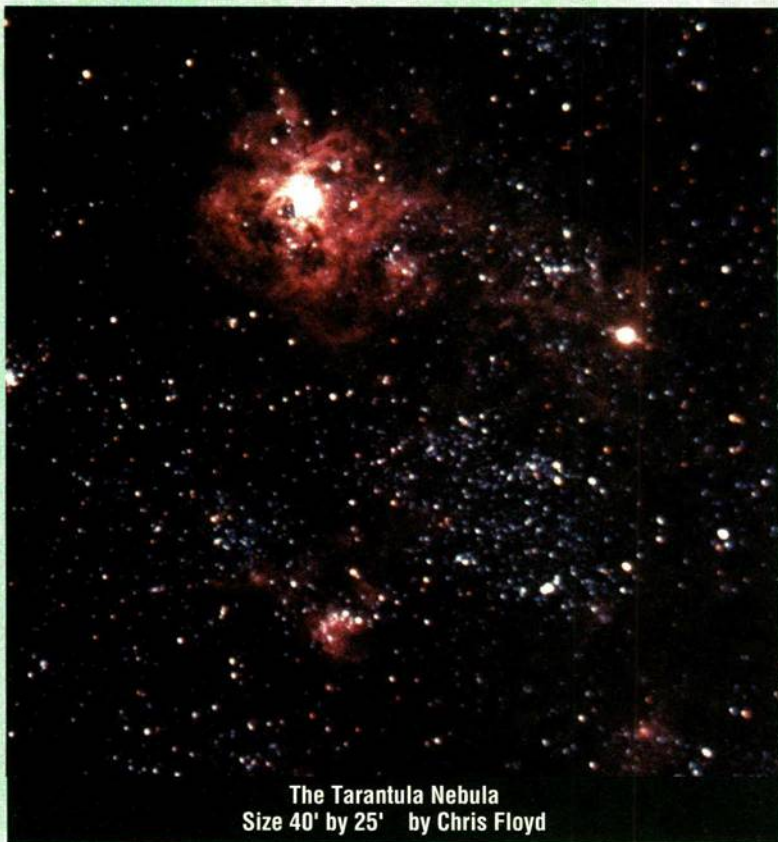
**The Jewel Box Cluster**  
**Mag. 4.2 Size 10' by Gregg D. Thompson**





Omega Centauri  
Mag. 3.7 Size 36.3' by Jack Newton





**The Tarantula Nebula**  
Size 40' by 25' by Chris Floyd

Perhaps the most spectacular galactic object in the southern sky is the **Eta Carinae Nebula** (NGC 3372), a giant rose-colored emission nebula that makes M42 in Orion look like kid's stuff. Prominently visible with the naked eye, the Eta Carinae Nebula fills a finder scope with glowing nebulosity extending over  $2^\circ$  in diameter. Placing an O III filter in my 12.5-inch scope helps me see the Eta Carinae Nebula as a large, bright complex of nebulosity involved with bright stars. Strands and wisps of light spanning a great range of surface brightness — from intensely bright to nearly imperceptible — dance across numerous fields of view.

At the center of the Eta Carinae Nebula lies the **Keyhole Nebula**, a small, very opaque dark nebula surrounded by extremely bright nebulosity. Surrounding the brightest star in the Eta Carinae Nebula — Eta Carinae itself — is a curious feature that seems to be a blur caused by poor optics to many first-time observers. This is in fact the **Homunculus Nebula**, a ruddy glow shaped like a bow-tie. This object is bright enough that it is visible as a rusty-red nebula even in an 8-inch scope. The Homunculus Nebula is best observed with high magnification under good seeing.

Many remarkable star clusters lie in the southern sky. There are many extremely fine, mostly unresolvable, naked-eye open clusters within  $20^\circ$  of Eta Carinae. **NGC 2516** is a dead ringer for the Beehive Cluster and needs only the slightest optical aid to resolve its one hundred stars. **IC 2391** and **IC 2602** are partially resolvable with the unaided eye and are best seen with small binoculars. **NGC 3114**, only  $4^\circ$  west of Eta Carinae, resolves into hundreds of faint stars in apertures larger than 10 inches. **NGC 3532** displays a bright



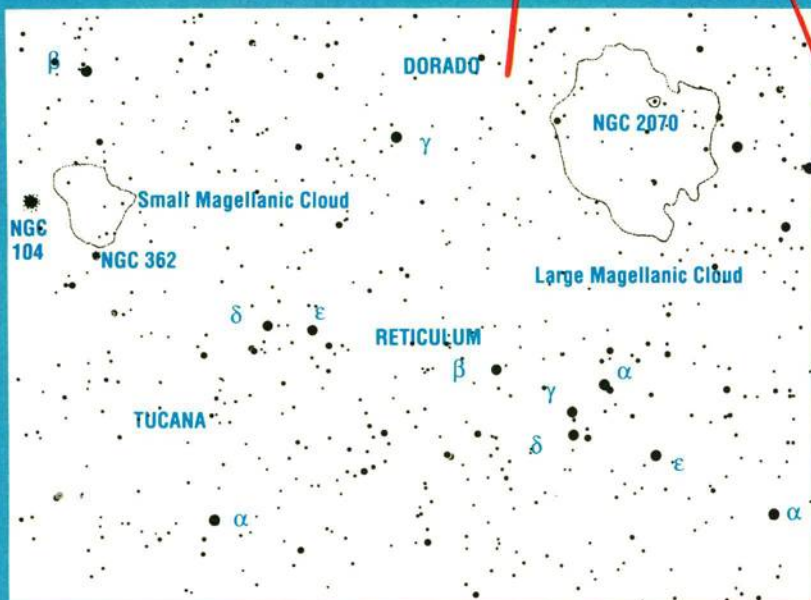
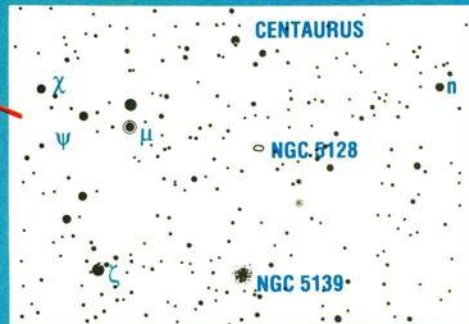
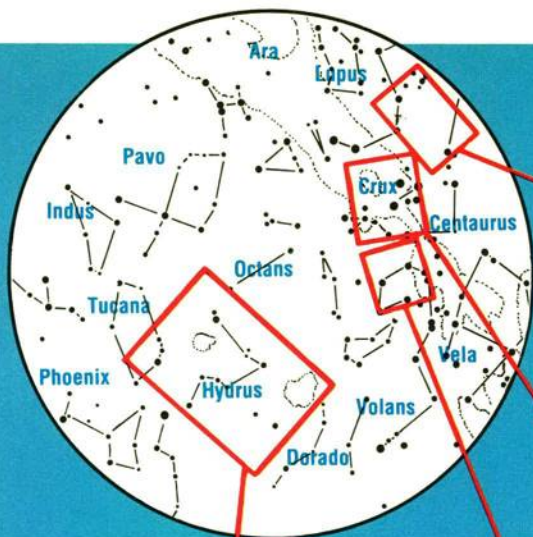




The Large and Small Magellanic Clouds  
Mags. 0.1 and 2.3 Sizes 650' by 550' and 280' by 160' by Ronald Royer



# The Southern Sky



## Wonders of the Southern Sky

| Object   | Type | R.A.(2000.0) | Dec.    | Mag. | Size        |
|----------|------|--------------|---------|------|-------------|
| NGC 104  | GC   | 0h24.1m      | -72°05' | 4.0  | 30.9'       |
| SMC      | Gal  | 0h52.7m      | -72°50' | 2.3  | 280'x160'   |
| NGC 362  | GC   | 1h03.2m      | -70°51' | 6.6  | 12.9'       |
| LMC      | Gal  | 5h23.6m      | -69°45' | 0.1  | 650'x550'   |
| NGC 2070 | EN   | 5h38.7m      | -69°06' | —    | 40'x25'     |
| NGC 2516 | OC   | 7h58.3m      | -60°52' | 3.8  | 30'         |
| IC 2602  | OC   | 10h43.2m     | -64°24' | 1.9  | 50'         |
| NGC 3372 | EN   | 10h43.8m     | -59°52' | —    | 120'x120'   |
| NGC 3532 | OC   | 11h06.4m     | -58°40' | 3.0  | 55'         |
| NGC 4755 | OC   | 12h53.6m     | -60°20' | 4.2  | 10'         |
| NGC 5128 | Gal  | 13h25.5m     | -43°01' | 7.0  | 18.2'x14.5' |
| NGC 5139 | GC   | 13h26.8m     | -47°29' | 3.7  | 36.3'       |
| NGC 6397 | GC   | 17h40.7m     | -53°40' | 5.7  | 25.7'       |

**Object:** Designation in NGC, IC, or other catalog. **Type:** Object classification; GC - globular cluster, OC - open cluster, EN - emission nebula, Gal - galaxy. **R.A. and Dec.:** Right Ascension and Declination for equinox 2000.0. **Mag.:** V magnitude. **Size:** Dimensions in arcminutes.

orange star in its center and another one at its edge. A dark void divides this cluster and makes it appear like a glowing arrowhead. **NGC 3766** is so compact that it looks like a 5th-magnitude star to the naked eye. It is rich with bright stars with several hues of blue and red. **NGC 3293** competes with **NGC 4755**, the famous Jewel Box cluster. Both are bright, compact star groups with two orange-red stars surrounded by a blue-white smattering of stars.

With so many outstanding examples of clusters, nebulae, and galaxies visible from the Southern Hemisphere, it's certainly worth a visit at some point in your life. As a visitor your observing time will be precious so list the things you want to see and plot them on an atlas ahead of time. But be warned: After seeing what the southern sky holds, you may never want to return to the North!

*Gregg D. Thompson lives in Queensland, Australia, where he has observed the southern sky for over twenty-five years. He is coauthor of the book Supernova Search Charts and Handbook, published this year by Cambridge University Press.*



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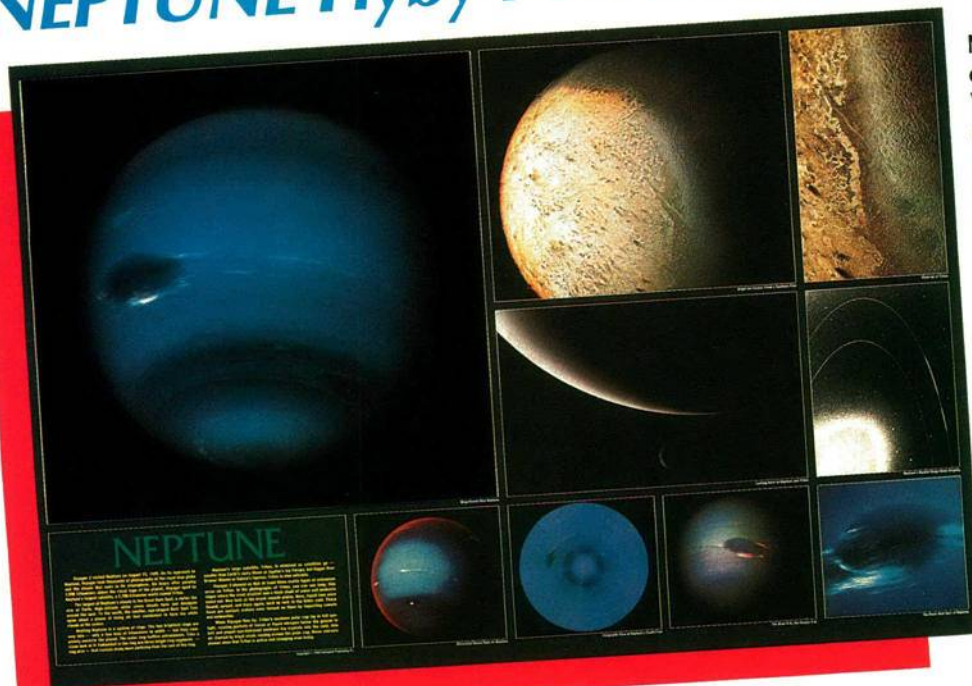
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◀ The Orion Nebula, photographed by Tom Orzechowski.

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Brilliant, fast-changing auroral displays occurred in both hemispheres in October and November 1989, and were observed by hundreds of sky-watchers. These prominent aurorae resulted from the recent high level of solar activity as the Sun moves toward peak activity this spring.

"It was my first auroral sighting since becoming an amateur astronomer fifteen years ago," said David Headland of Victoria, Australia. "During the early morning of October 21 I witnessed a tremendous aurora that glowed with a rose color and at times appeared to have green and blue hues. The aurora shimmered irregularly and stretched between Alpha and Beta Centauri to the opposite side of Crux."

On the same night M. L. Clark observed the aurora from Armadale, Western Australia. "At 8:00 p.m. I went outside with Cliff Dacey of the Murdoch Astronomical Society and as soon as we dark-adapted we saw a large glow in the southern sky. "After a few minutes we saw that the glow was decidedly pink in hue and extended about 10° above the southern horizon. By 9:15 p.m. the aurora had died down. We were quite chilly but stayed outside to observe 47 Tucanae, NGC 55, NGC 253, NGC 288, and other deep-sky objects," Clark reported.

"At 10:00 p.m. the situation changed considerably. I was observing galaxies in Fornax when Cliff noticed that the aurora was brightening and turning green. A few minutes later it seemed like the sky exploded. A bright ray appeared below Canopus, lengthening and brightening quickly, and reached up past the Large Magellanic Cloud. At the same time the glow to the south brightened and increased in size. The southern glow turned strongly pink in color and stretched from Columba to the stinger of Scorpius. Higher in the sky nine sharply defined rays were visible.

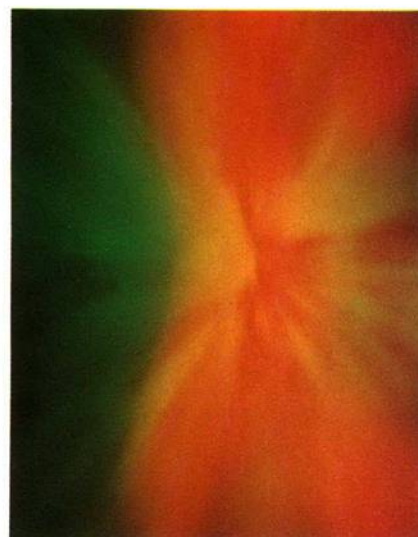
"By 10:20 p.m. the sudden burst of auroral activity began to diminish. Curiously, each time a ray faded a fainter ray formed several degrees to the west. The activity halted as suddenly as it had begun, and by 10:45 p.m. the only activity was a faint glow several degrees above the southern horizon. We packed up our equipment and left for the night, hoping that we would be so lucky some other night."



**SHIMMERING RED AURORAE** were a frequent sight last winter in both Northern and Southern hemispheres. On October 20, 1989, aurora australis blanketed much of the southern sky, including the Magellanic Clouds. Photo by Gordon Garradd.



**CRUX AND CENTAURUS** lie engulfed by bright aurorae in this October 20, 1989, photograph by M. L. Clark.



**A STRONG OVERHEAD DISPLAY** of aurora borealis was captured by Jack and Karen Fredricks on November 17, 1989.



## THE SKY ABLAZE WITH AURORAE

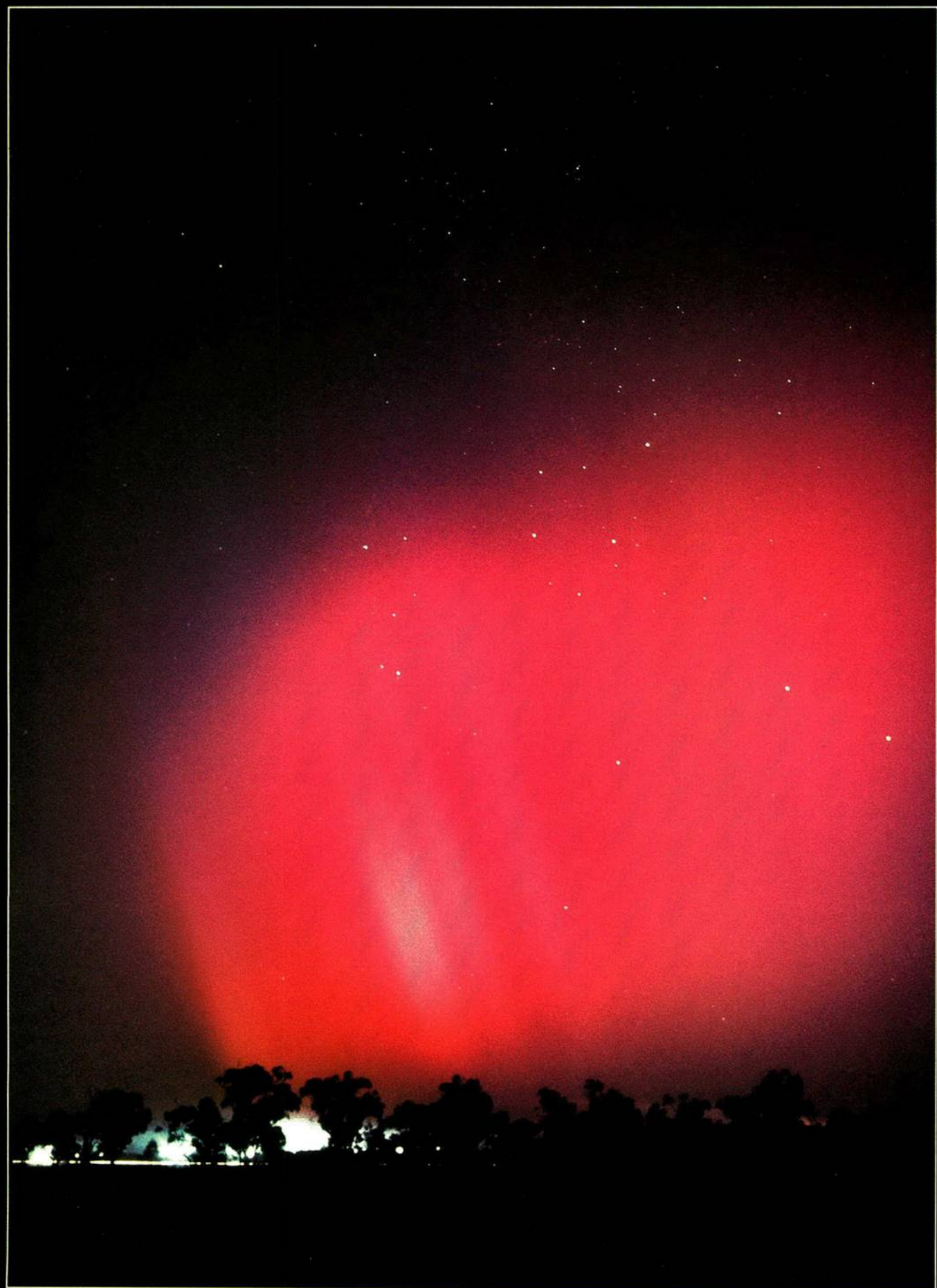
Aurora australis turned the sky surrounding Crux and Alpha and Beta Centauri a vivid rose-pink on the night of October 20, 1989. David Headland's photo of the brilliant display (opposite page) receives this month's \$100 "Best Astrophoto" award. Headland, an observer from Victoria, Australia, used a 55mm f/4.5 lens, Fujichrome 400D Professional film, and a 30-second exposure.

As Comet Okazaki-Levy-Rudenko brightened to 6th-magnitude and its tail stretched to several degrees in length, numerous astrophotographers recorded the comet on film. On November 8, 1989, Ronald Royer used an 18-inch f/7 reflector and fine-grain Tech Pan film to capture details in the comet's tail (below). On the following night Chris Schur used a Schmidt camera to record the comet's complete tail (below left).

Jupiter's usually prominent South Equatorial Belt remained invisible throughout November 1989, as Gregory Terrance's photo of the planet made on November 22 (left) illustrates. Another curious and rare phenomenon is the green flash, an optical effect visible when atmospheric conditions are just right at sunrise and sunset. Robert E. Schalck caught the green flash on September 2, 1989, from California's Fremont Peak State Park (bottom).







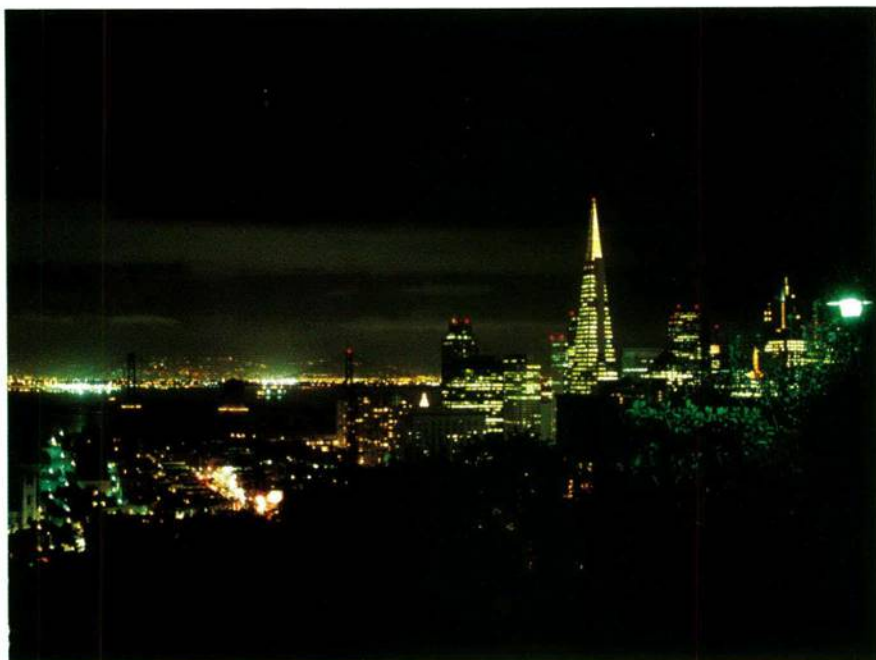


## THE MILKY WAY OVER SAN FRANCISCO

"Who says you have to be away from the city to photograph celestial objects," said Nathan T. Wong of San Francisco. "During October 1989 I made a series of astrophotos from the heart of San Francisco, and in each I can identify enough stars to trace out a constellation."

Wong was operating under extraordinary conditions, however. "Okay, I admit that a few of the slides were made during the citywide blackout that followed the October 17 earthquake. It was so dark during the blackout that we saw the Milky Way from downtown! But the most spectacular shot was taken a week later when the lights of San Francisco were back on, providing a foreground for the rising Orion.

"On October 23 a thunderstorm had just ravaged the Bay Area. As the rain clouds moved over Oakland they blocked lights from the Port of Oakland, giving me the rare opportunity to photograph Orion as it rose over the lights of

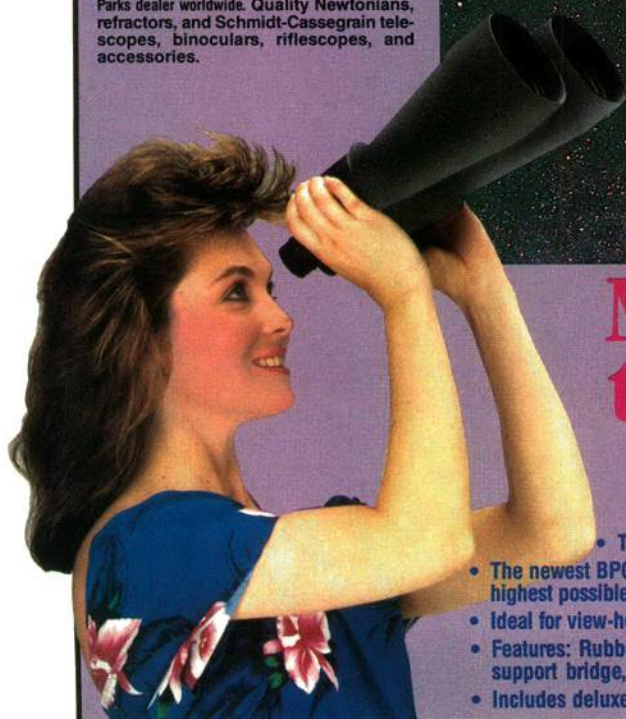


**ORION MAJESTICALLY RISES** over a partially blacked-out San Francisco six days after the October 17, 1989, earthquake. Photo by Nathan Wong.



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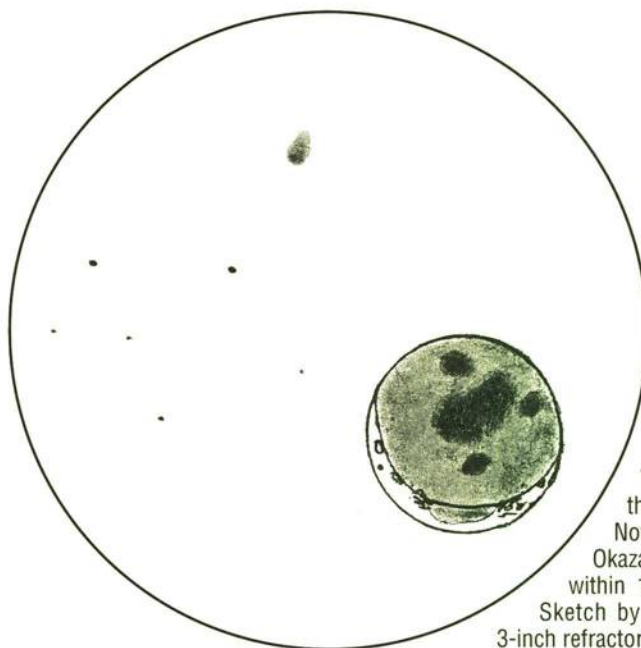


San Francisco. Those familiar with the city will see that the Bay Bridge, damaged during the earthquake, was closed and that some buildings still did not have lights on six days after the quake."

## THE MOON MEETS COMET OKAZAKI-LEVY-RUDENKO

"I was dead tired but simply had to get up to see this event," said Tom J. Martinez of Cleveland, Missouri. "It was November 24, 1989, and my computer program had predicted that Comet Okazaki-Levy-Rudenko would pass very close to the Moon. My alarm went off at 5:30 a.m. and I tumbled out of bed and got my binoculars.

"I found that I could view the Moon from my enclosed balcony, avoiding the chill of the early morning air. I propped my 11x80 binoculars against a rail and instantly found the beautiful crescent Moon. Indeed, the comet lay about 1.5° northeast of the Moon. It was a conspicuously fuzzy object compared to the sharp pinpoints of starlight



## A FUZZY COMET AND THE MOON

were paired in the early morning sky on November 25, 1989. Comet Okazaki-Levy-Rudenko passed within 1.5° of the Moon's limb.

Sketch by Larry McHenry using a 3-inch refractor at 21x.

surrounding it. I found the 6th-magnitude comet with amazing ease despite the bright Moon lying within the same field of view.

"The comet appeared to be about the same magnitude as the star 50 Virginis, which lay a degree east of the comet. I

also compared the comet with 62 Virginis, but by this time the increasingly bright twilight was washing out the sky, which made estimating magnitudes difficult. The comet was definitely brighter than 62 Virginis, a star that glows at magnitude 6.7." — David J. Eicher □

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Robert W. Smith with  
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## THE GOD FACTOR

I recall it was the third lecture in astronomy I'd ever given and the topic was the Big Bang. After the talk a youthful questioner shattered my veneer of scientific objectivity by asking, "Do you believe in God?"

At first I thought I had misheard so I asked her to repeat the question. She obliged, somewhat louder this time. "Do you believe in God?"

This was one question I had not anticipated, although in hindsight I see the talk was tailor-made for it. I needed time to gather my wits.

"Pardon me," I asked, "but why do you ask that particular question?"

The young lady looked at me steadily and replied, "Because throughout the entire lecture you've gone into great detail about how this or that body originated, but not once did you refer to God in any of it!"

I replayed the lecture in my mind, trying to see it from her perspective. After a moment I gave a reply which, incidentally, has not changed significantly since. First of all, I explained that science is founded on principles, concepts, and hypotheses that are verifiable or at least measurable. God, as a supernatural entity, did not fall into these categories. Indeed the success of science has stemmed largely from a judicious selectivity in the problems it investigates.

This selectivity excludes problems for which no practical way of inquiry exists. I pointed out that so far as we know, physical inquiry can only be applied to physical phenomena. Consequently, no supernatural entity is a fitting subject for scientific investigation.

Does this mean that all scientists are atheists? Not at all! But it does mean that a careful scientist tries not to mix personal beliefs with scientific work. Observations of the natural world should be independent of any personal belief system based on the unproven existence of the supernatural.

My second point to the young lady was that even if we agreed some ultimate power started it all, there would still be no agreement on that power's nature. I may see it as impersonal: a sub-quantum energy domain on the scale of the Planck length ( $10^{-33}$  centimeters). She may see it as a wholly personal being, i.e. God in the traditional Jewish or Christian sense. Neither of us could convince the other of our God-concept's validity. To put it another

way, no human mind is 100 percent perfect, so no human mind is capable of knowing an absolute. Hence, all God-concepts emerge as relative and none can be upheld logically as true if it excludes all others.

Of course, none of this satisfied the young lady. My reply did nothing to reinforce her personal belief system. Instead it offered her an ongoing uncertainty, which many find unacceptable.

The experience prompted me to see what astronomers and physicists had to say on the matter. The results are as interesting as they are diverse. In his 1961 book *The Nature of the Universe*, Fred Hoyle dismissed believers by presenting a case to show why God was redundant and unnecessary. Unfortunately, Hoyle

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### An individual God factor enters each of our minds when we regard the immensity of the universe.

---

based his argument on his steady-state cosmology which postulated that matter was continually created and the universe had no beginning or end.

Not surprisingly, many atheists agreed. But by 1965 the steady-state universe was defunct thanks to Penzias and Wilson's discovery of the  $3^\circ$  microwave background radiation, which strongly supported the Big Bang model.

By 1983 Hoyle had become a believer of sorts. In his book *The Intelligent Universe*, he attacked Spencer's version of Darwinian evolution, in which life evolves from organic chemicals through improbable, random events over a long time. Hoyle concluded that a "superior intelligence" is guiding life in a computerized sort of way.

Quoted in a 1983 *Time* article, Hoyle stated, "I believe we are the emergence of software that has basically been designed by another intelligence, probably to represent itself. In a way, software is the soul."

After reducing soul to software, Hoyle compared both the extreme scientific and extreme religious points of view, saying, "[Organized religions] see Judgment Day as God sitting there with a wig on, in a big chair. The religious side is wrong because it wants to see



too much too soon. The scientific side is wrong because it lacks the imagination to see what might be possible."

But physicist Paul Davies has thought about what might be possible. In a 1983 *New Scientist* article, he noted that "the new physics projects God outside matter, space, and time into the abstract world of logic, mathematics, and physical law. It has no need of a Creator in the traditional sense, but seems to demand some guiding influence located, as it were, above nature."

Astronomer Alan Batten said in a 1984 paper in the *Journal of the Royal Astronomical Society of Canada* that the question of how the universe came to be cannot be separated from questions of whether it has a purpose and what our relationship to it might be. Batten also claims our secular scientific society may have "called forth Creationism as a corrective to itself."

"My impression is that many of the biologists who write about evolution for the ordinary public are committed in their minds to the belief that the question 'Why?' has no answer," wrote Batten. "[They believe] evolution is purposeless, and life and Man have arisen only by chance." Of course, he noted, "this is a legitimate belief for a person to hold, but that it is required by the scientific evidence is highly questionable. To hold it is as much an act of faith as to maintain the opposite."

Batten recommends we stop trying to argue with creationists from a purely scientific stance. According to him, "I believe we shall achieve much more by frankly admitting the limitations of scientific research and concede that even creationists are raising legitimate questions."

These questions appear to me to be fundamentally religious because they invoke supernatural agents to account for natural phenomena, a process that is poles apart from how science is carried out. In fact, as generally practiced, science and religion are mutually exclusive and are, in effect, speaking different languages.

A. J. Ayer, in his book *Language and Logic*, commented that the basis for all belief arises from a highly subjective background. Faith is not constituted of elements that can be dissected or quantified, which relieves the religious person from having to defend every belief on a rational or scientific basis.

Creationism fails precisely because it presents personal belief as a rational field of inquiry. But creationism has already answered all its nature-of-the-

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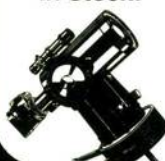
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world questions so it really has no need to inquire further. My point is that once creationism is acknowledged as religious belief, it can be taught properly as such in Bible study classes and Sunday school. There is, therefore, no need for it to try to compete with astronomy or any other science in a classroom.

Taking this step would spare us the spectacle of creationists making lame and unconstitutional attempts to get "creation science" into the curriculum. This would also afford some protection for creationism and other religious views. In particular, it would mean that scientists, speaking as rationalists, could not make meaningful statements about God as a supernatural concept.

Stephen Hawking, in his recent best-

## The new physics has projected God outside matter and space into the world of mathematics and physical law.

seller *A Brief History of Time*, outlined his own theory of an unbounded universe with neither beginning nor end, and asked, "What place then for a creator?" He thereby places a scientific understanding of physical reality on a higher plane than the religious. You may feel this is true, but as physicist Bernard d'Espagnat cautions in his book *In Search of Reality*, "Every kind of understanding need not necessarily be intellectual. Our intelligence is not transcendent. It has been formed by evolution in the same way as our muscles or our skeleton."

In the end, I suspect a "God factor" of some kind enters the mind of each of us when we regard the immensity of the universe and ponder its relation to us. We need to bear in mind that this God factor is uniquely individual because each of us sees a different view through our personal window on the cosmos.

The lesson for all of us involved in scientific pursuits is not to let the objective cloaks we wear blind us to subjective concerns. It may well be that the entire scientific enterprise represents a faith of another sort, a faith that the methods we use actually bring us closer to objective truth, whatever that is.

And maybe, just maybe, this objective truth and the believers' God are one and the same thing. — Philip A. Stahl



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## READER EXCHANGE

**WANTED** — Jan/Feb 1989 issues of SPACE FLIGHT NEWS. Need to complete set. Willing to pay more than cover price. Contact D. Dimmock, 189 Otipua Road, Timaru, New Zealand.

**WANTED** — Correspondence with amateur astronomers worldwide. Interests are planetary and deep-sky objects, UFO phenomena, computers, and science fiction. Contact Dan Duchnych, 5 Harwich Road, Flanders, NJ 07836. Phone (201) 927-1117.

**WANTED** — Early issues of COUNTDOWN Mag. volumes 1-3, volume 4, #1. Contact R.A. Marino, 3401 Avon Ct., Ft Collins, CO 80526. Phone (303) 223-3784.

**NOTICE** — April 27-29, 1990. The third annual "Southern Star" conference will be hosted by the Charlotte Amateur Astronomers at Wildcross retreat, Blue Ridge Mountains of N.C. David Levy, Gerrit Verschuur, and Sheridan Simon will be among the guest lecturers. Observing under clear, mountain skies will be featured. Contact Ron Simpson, 7626 Gayle Avenue, Charlotte, NC 28212. Phone (704) 536-9595.

**NOTICE** — The Great Christmas Gift Show-off, Museum of York County, Rock Hill, S.C. Sponsored by the Carolina Skygazers Astronomy Club. Contact Leon Knott, 4621 Mt. Gallant Road, Rock Hill, SC 29732. Phone (803) 329-2125.

**ANNOUNCEMENT** — Hunting for astronomy software for your Macintosh, Atari XL/XE/ST, or Amiga computer? We have several public domain disks available for trade or \$4.00 each. Send S.A.S.E. specifying computer type for our list. Contact Dan, Russell or Jan, P.O. Box 1646, Orange Park, FL 32067-1646.

**ANNOUNCEMENT** — Astronomy Day celebration on April 28. Exhibits, talks, shows, demonstrations, and a star party sponsored by the Northwest Suburban Astronomers in Hoffman Estates, Illinois. Contact Michael D. Mangan, 208 Islington, Schaumburg, IL 60193. Phone (708) 980-0080.

**ANNOUNCEMENT** — The Royal Astronomical Society of New Zealand will hold its annual conference in Christchurch on May 11, 12, and 13, 1990. The conference is being hosted by the Canterbury Astronomical Society and will be held at the Canterbury University. Christchurch is not far from the mount John Observatory at Black Birch. Contact Mr. Lionel Hussey, c/- 52 Fleete Street, Christchurch, 8006, New Zealand.

**ANNOUNCEMENT** — New members sought! The Northwest Suburban Astronomers meet monthly in Hoffman Estates, Illinois. NSA is seeking to increase its 125+ membership. Men and women of all ages and levels of expertise are welcome. Join the winners of the 1st Annual National Astronomy Day Award. Contact NSA, V.P. Programs, Tom Quinn, 631 Delaware Lane, Elk Grove, IL 60007. Phone (708) 894-3750.



## STORIES OF THE OUTERMOST PLANETS

*Planets Beyond: Discovering the Outer Solar System* by Mark Littmann, (John Wiley and Sons, 1989), ISBN 0-471-61128-X, hardcover, 286 pages, \$22.95.

*Planets Beyond* is the story of discoveries made by man, mind, and scientific instruments. Mark Littmann chronicles the discoveries of the three outer planets — Uranus, Neptune, and Pluto — and the impact these discoveries had on the astronomical community at the time. Interwoven among the stories are fascinating insights into the personalities of the scientists who searched the outer solar system. In addition, Littmann looks at how their discoveries were received by other, sometimes not-so-gracious astronomers. Sir George Airy's treatment of John Couch Adams and the subsequent uproar over the mathematical discovery of Neptune is a revealing account of the clash between the old guard and a pioneer of a new field.

In chapters 7 through 11, Littmann recounts *Voyager 2*'s epic journey of exploration. Interesting vignettes by members of the *Voyager* team detail the problems and objectives of the mission as well as chronicle the discoveries the spacecraft made at Uranus. Also included are scientists' predictions about what they might find at Neptune. Because the book was written before *Voyager 2* reached Neptune, it is interesting to compare these expectations with what was actually found by *Voyager 2*. Littmann supplies the reader

with a "scorecard" for such a comparison on page 158.

The book closes its discussion of *Voyager 2* with a chapter on the spacecraft's mission beyond the solar system. Littmann relates what scientists expect to find as it and its sister craft, *Voyager 1*, encounter the far-flung region where the Sun's gravitational and electromagnetic influence give way to interstellar space.

The final chapters of the book address what remains to be learned about the outer solar system. Chapter 12 examines Pluto and how it has both confounded and astonished planetary astronomers since its discovery. Included is a fascinating hypothetical tour of the planet by a future manned mission.

Chapter 13 assesses the prospects for the discovery of a tenth planet, the evidence for and against its existence, and the pitfalls that the search for such a planet must avoid. The final chapter covers what we have learned about the outer solar system and how it relates to what astronomers already know about its formation. Included are discussions about future missions to Jupiter (*Galileo*), Saturn (*Cassini*), and comets (*CRAF*), and what these missions will add to our understanding of the solar system.

Mark Littmann succeeds in conveying the excitement of the continuing exploration of the solar system and the thrill of discovery, whether those discoveries are made by man, mathematics, or tiny robot spacecraft billions of miles from their home planet. This is an engaging and revealing account of our first steps toward exploring the outer planets. — *Michael Porcellino*

### PROFILES OF A FEW HISTORIC STARS

*Astronomers' Stars* by Patrick Moore, (W. W. Norton, 1989) ISBN 0-393-02663-9, hardcover, 164 pages, \$17.95.

Bringing the stars down to Earth is not an easy task for any science writer, but Patrick Moore has done a good job of it in *Astronomers' Stars*. The book is a pleasant balance of history, basic astrophysics, and personal observations that takes the bite out of the complex subject of stellar astronomy.

Moore profiles sixteen stars and de-

scribes what astronomers have learned about these individual points of light from decades of studying and observing. Each star, it seems, has its own story to tell. The famous high proper-motion double star 61 Cygni speaks of the problems astronomers have had in determining stellar distance and parallax. Vega and its surrounding ring of dust played a role in what we know about the possible formation of other solar systems. And the red giant Betelgeuse forms the basis for an explanation of stellar evolution and the Hertzsprung-Russell diagram.

Other popular stellar players featured in Moore's book are Sirius, Mizar, Algol, and Mira. The reader already familiar with these stars will realize that Moore is touching on almost every aspect of stellar astronomy. Included are discussions of novae and supernovae, black holes, pulsars, and quasars. A nice touch is the inclusion of finder charts for all of the stars discussed. To turn your telescope on Vega, for example, and think about its dust ring and possible planets adds an intriguing dimension to observing.

Astrophysical principles are clearly presented and should be understandable to the reader new to this field. The only exception I found was a tangled discussion of Cepheid variables and how they are used to determine distance.

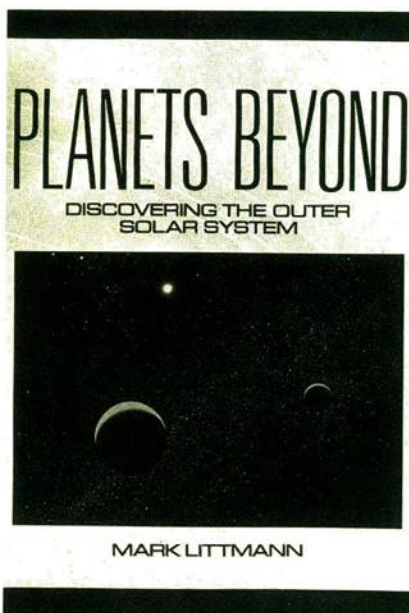
Moore goes to great lengths to present the human side of the astronomers who played key historical roles in stellar research. By showing them as people, Moore emphasizes that science is a human endeavor that does not always advance along a straight path. Scientists can be, and often are, wrong.

I enjoyed this book and recommend it as a resource for both the armchair astronomer and the active observer. *Astronomers' Stars* is not only good history, it is also an in-depth account of our understanding of the stars and the astronomers who study them. — *Michael Porcellino*

### BOOKS RECEIVED

#### General Astronomy

*Astrology and Astronomy* information packet, (Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112), ISBN 0-937707-00-7, pamphlet, 15 pages, \$4.00. □





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## Astronomy Products

### SLIDE SETS



**Astronomers of the Past slide set**, (Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112; (415) 337-1100), 50 slides, \$47.95.

This slide set of black-and-white portraits of well-known astronomers such as Nicholas Copernicus, Galileo, and William Herschel also includes lesser-known figures such as Cecilia Payne-Gaposchkin, Edwin Hubble, and Rudolph Minkowski. (As the title hints, no living astronomers are included.) The set comes with a 24-page booklet containing short biographies of each astronomer and a bibliography on the history of astronomy.

**Neptune Kit slide set**, (Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112; (415) 337-1100), 12 slides, \$17.95.

Subtitled "An Introduction to the Planet Neptune after the Voyager 2 Encounter," this slide set presents the best dozen photos from the flyby. Eight slides are in color, two of which show Triton. Other subjects include the Great Dark Spot, the Lesser Dark Spot, a composite ring image, flooded basins on Triton, and cloud shadows on Neptune. A 32-page booklet by astronomer William Kaufmann provides descriptions of each slide, a reading list on Uranus and Neptune, and some suggested classroom activities.

### TECHNICAL INFORMATION

**Charge-Coupled Devices for Quantitative Electronic Imaging**, (Photometrics

**STELLAR SPECTROSCOPIST** Annie Jump Cannon, from the *Astronomers of the Past* slide set.

Ltd., 2010 N. Forbes Blvd., Tucson, AZ 85745; (602) 623-8961), free.

This 28-page booklet describes the theory and application of CCD imagers for tasks that require highly linear response and a large dynamic range. Performance limitations are fully discussed, together with calibration and noise-reduction techniques.

### MISCELLANEOUS

**The Celestial Planisphere jigsaw puzzle**, by Tomas J. Filsinger, (Great American Puzzle Factory, 16 S. Main St., South Norwalk, CT 06854; (203) 838-4240), 1,000 pieces, \$15.00.

This puzzle shows the northern and southern celestial hemispheres in color with glow-in-the-dark stars plotted in seven magnitude steps. It measures 20 by 27 inches, and includes a 30-page booklet that describes map projections, sky coordinates, deep-sky objects, and the history of celestial cartography.

**Saturn wall hanging**, (Auriga S.r.l., Via M.F. Quintilliano 30, 20138 Milan, Italy), cloth poster, 29,500 lire (about \$21), postpaid.

This wall hanging, made of a synthetic fabric, measures 65 inches by 88 inches. The image is by Japanese space artist Kazuaki Iwasaki and shows Saturn as seen from one of its moons. □



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## Readings and Resources

### Venus (page 18)

"The Geology of Venus," by Aleksandr Basilevsky and James W. Head III, in *Annual Reviews of Earth and Planetary Sciences*, volume 16, 1988 (Annual Reviews, Inc., 1989). Detailed, up-to-date review of Venus geology written by two leading Venus scientists.

*Venus: An Errant Twin*, by Eric Burgess, (Columbia University Press, 1985). Explains Venus for the interested layman. Contains a comprehensive overview of Venus and a detailed history of the space missions sent there.

*Venus*, edited by Donald M. Hunten, et al, (University of Arizona Press, 1983). A 1,140-page anthology of professional-level papers on all aspects of Venus. Contains several review papers accessible to lay readers. Does not include data from the Soviet *Venera 15* and *16* missions.

*The Planetary System*, by David Morrison and Tobias Owen, (Addison-Wesley, 1988). College-level survey of the entire solar system, from Mercury to the Oort cloud of comets. Has a chapter comparing Venus and Earth.

*Planetary Landscapes*, by Ronald Greeley, (Allen & Unwin, 1987). Heavily illustrated guide to geological processes on each of the planets. Includes a chapter on Venus.

### Solar Neutrinos (page 40)

*Neutrino Astrophysics* by John N. Bahcall, (Cambridge University Press, 1989). An account of solar neutrinos, the reactions that produce them, and experiments designed to detect them.

"Insight into Star Death" by Richard Talcott, *ASTRONOMY*, February 1988. A nontechnical account of the neutrinos produced by supernova 1987A, how they were detected on Earth, and what their discovery meant to astronomers studying stellar evolution.

### Astro-Slides (page 66)

*Basic Developing, Printing, Enlarging in Color* (Eastman Kodak, 1984). A beginner's guide to color darkroom work; includes charts to help you assess color and exposure corrections.

### Explore the Southern Sky (page 72)

*Astronomical Objects for Southern Telescopes* by E. J. Hartung, (Cambridge University Press, 1968). An Australian observer's meticulous notes about deep-sky objects found in the southern sky.

*Exploring the Southern Sky* by Svend Laustsen, Claus Madsen, and Richard M. West, (Springer-Verlag, 1987). A gorgeous picture book filled with colorful observatory photographs of the finest objects in the southern sky. □

## CREDITS

Cover: Cerro Tololo Inter-American Observatory; page 4: Forrest Baldwin (50mm f/1.4 lens, Ektachrome 400 film, 4-second exposure); page 12: European Southern Observatory; pages 20-25: U.S. Geological Survey (Flagstaff), image processing by Alfred McEwen; page 26: Donald Campbell, Arecibo Observatory/National Astronomy and Ionosphere Center; page 27: U.S. Geological Survey (Flagstaff), image processing by Alfred McEwen, radar data from Donald Campbell, Arecibo Observatory/National Astronomy and Ionosphere Center; page 28: USSR Academy of Sciences; page 30: National Radio Astronomy Observatories; page 42: observations from Raymond Davis' solar neutrino experiment, courtesy of John N. Bahcall; page 52: Forrest Baldwin (50mm lens at f/1.4, Ektachrome 400 film, 3-second exposure); page 55: Andrew W. Steinbrecher (16-inch, f/5.5 reflector stopped to 6 inches, Mylar solar filter, Tech Pan film, 1/250-second exposure); page 60: Chris Becker; pages 67-69: Robert Bunge; page 72: Chris Floyd (50mm f/2 lens, 50-minute exposure); page 73: Ronald Royer (4-inch f/5 lens, tricolor integration print); page 74, top: Jack Marling (24-inch f/7.5 Cassegrain, Fujichrome RD 100 film, 50-minute exposure), bottom: Gregg D. Thompson (10-inch reflector, 10-minute exposure); page 75: Jack Newton (14-inch f/7 SCT, cold camera, 14-minute exposure); page 76: Chris Floyd (10-inch f/4.5 reflector); page 77: Ronald Royer (50mm f/1.4 lens, 200 ISO film, 33-minute exposure); page 81, top: Gordon Garrard (16mm f/2.8 lens, Kodachrome 200 film, 20-minute exposure), bottom left: M. L. Clark (50mm f/2 lens, Fujichrome 1600 film, 90-second exposure), bottom right: Jack and Karen Fredricks (24mm f/2.8 lens, 100 ISO film, 60-second exposure); page 82, top: Gregory Terrance (16-inch f/5 reflector at f/83, Tech Pan film, 1-second exposure), middle left: Chris Schur (8-inch f/1.5 Schmidt camera, hypered Tech Pan film, November 9, 1989), middle right: Ronald Royer (18-inch f/7 reflector, 103a-O film, 11-minute exposure), bottom: Robert E. Schalck (400mm f/18 lens, Kodak Gold 100 ISO film, 1/250-second exposure); page 83: David Headland (55mm f/4.5 lens, 800 ISO film, 30-second exposure); page 84: Nathan Wong (35mm f/2 lens, Kodachrome 64 film, 15-second exposure); page 85: Larry McHenry (3-inch f/13 refractor at 21x, November 25, 1989, 6:25 a.m. EST).



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## February 22

**Galileo: A Jovian Odyssey**, Toronto, Ontario. Lecture sponsored by The Planetary Society. Contact: Hema Murty, 5949 Yonge Street, #506, Willowdale, Ontario, Canada M2M 3V8. Phone: (416) 225-9143.

## March 14

**New England Astronomy Teachers' Organization meeting**, Cambridge, Massachusetts. Contact: Darrel Hoff, Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, or James C. Kernohan, NEAT, 170 Centre Street, Milton, MA 02186. Phone: (617) 698-7800.

## March 17

**Electronics-Oriented Astronomy 3**, Chapman College, Orange, California. Sponsored by the Orange County Astronomers. Contact: John Sanford, 2215 Martha Avenue, Orange, CA 92667.

## March 22-25

**3rd Annual Chieftland Star Party**, Chieftland, Florida. Sponsored by the Tampa Area Astronomy Society. Contact: John Novak, 9890 82nd Street North, Largo, FL 34627. Phone: (813) 392-4669 or (904) 493-9036.

## April 24-27

**27th Space Congress**, Cocoa Beach, Florida. Sponsored by the Canaveral Council of Technical Societies. Contact: Canaveral Council of Technical Societies, P.O. Box 321333, Cocoa Beach, Florida 32932.

## April 28

**Astronomy Day**. Contact: Gary Tomlinson, Astronomy Day Coordinator, Astronomical League, Chaffee Planetarium, 54 Jefferson Avenue SE, Grand Rapids, MI 49503. Phone: (616) 456-3985.

## May 20-28

**Texas Star Party**, Prude Ranch, Fort Davis, Texas. Contact: TSP Registrar, Department A, P.O. Box 386, Wylie, TX 75098.

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## May 22-27

**The 10th Annual International Space Development Conference**, San Antonio, Texas. Sponsored by the National Space Society and the Southwest Research Institute. Contact: Carol A. Luckhardt, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78228-0510. Phone: (512) 522-3823.

## July 13-15

**Symposium on Automated Telescopes and Global Networking**, Boston University, Boston, Massachusetts. Contact: Meeting Information, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112.

## July 13-18

**Astronomical Society of the Pacific annual meeting**, Boston University, Boston, Massachusetts. Contact: Meeting Information, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112.

## July 14-15

**The Universe in the Classroom**, Boston University, Boston, Massachusetts. Contact: Workshop Information, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112.

## July 8-12, 1991

**Research Amateur Astronomy Symposium**, La Paz, Baja California Sur, Mexico. Contact: Corporation for Research Amateur Astronomy, P.O. Box 16542, San Francisco, CA 94116.

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**FOR SALE** — We have a LIFT-OFF by Ed Case. A historical documented book of reference of the first 26 NASA shuttle launches. 100 color photographs, 192 pages. \$9.95 plus \$2.00 postage. Contact Ed Case, 233 Harvey Avenue, N.E. Palm Bay, FL 32905.

**FOR SALE** — Orion 10x70 MC Binoculars. Includes hard leather case, caps, tripod mounting adapter. \$205 including shipping. Contact Jim Brumfield, 370 N.E. 7th Street, Linton, IN 47441. Phone (812) 847-8207.

**FOR SALE** — 10x70 Binoculars. Orion MC enhanced with BAK-4 prisms and fully multi-coated optics. Tripod bracket. Mint condition. \$195. Contact David Clemens, 251 Parkiomen Avenue, Schwenksville, PA 19473.

**WANTED** — Space memorabilia collector is seeking to obtain a piece of the space shuttle Challenger. Will pay or trade. Contact Dennis K. Bylina, 6355 Lange Drive, Colorado Springs, CO 80918.

**WANTED** — Your views, ideas, and information on if you want to see some real action for space exploration. Are you tired of seeing NASA with a small budget and nothing ever being done? Contact Michael Doss, P.O. Box 203, Pasadena, TX 77501-0203.

**WANTED** — Sixteen-year old seeks correspondence with anyone, anywhere, of any age who is interested in astronomy, Macintosh/Apples, and/or books by Douglas Adams. All letters will be answered. Contact Kersti Anear, 49 Millewa Cres., Dallas, Victoria, 3047, Australia.

**WANTED** — The Amarillo Astronomy Club is in need of a replacement drive gear for a Criterion Dynamax 8. Any information will be greatly appreciated. Contact Alan Scruggs, 1953 Howard, Amarillo, TX 79106. Phone (806) 352-4265.

**WANTED** — Photographs of the Soviet space shuttle Buran. Have materials on U.S. space program to trade. Also want contact with persons interested in the Soviet space program and especially would like to make contact with space enthusiasts in the Soviet Union. Contact Tim Linder, 127 Edgewood Avenue, Landrum, SC 29356.

**WANTED** — People in the southeast Texas area and the southwest Louisiana area interested in forming an astronomy club. Contact Kevin Swift, 2025 International, Apt. #10, Orange, TX 77630. Phone (409) 883-3298 or Kurtis Gothveaux (318) 478-1217.

**FOR SALE** Celestron 20x80mm binoculars. Latest Red Band model. Like new. \$240. Contact Selwyn Malin, P.O. Box 672, New York, NY 10023. Phone (212) 874-8406.

**FOR SALE** — ASTRONOMY May 1978-1988, \$100. LPR Filter \$30. Series 6 Filter Set \$30. Postage not included. Much more for sale. Contact George Adornato, 8409-109 Avenue, Ozone Park, NY 11417. Phone (718) 845-8388.

**FOR SALE** — Meade 2080 LX5 - complete, rarely used, excellent condition, plus dec, motor, moto focus, dew shield, LPR filter, 4 televue plossls. \$1,300 or best offer. Contact John Raustadt, 3313 Mumford Road, Minneapolis, MN 55429.

**WANTED** — Twenty-eight-year-old amateur astronomer would like to correspond with other worldwide astronomers. Contact Hwang Jun ho, 137-19 Duryu-2-Dong, Dalseogu, Daegu, Korea

**FOR SALE** — Telescope Making 1-30 \$75; DEEP-SKY 1-25 \$65. Contact Hwang Jun ho, 137-19 Duryu-2-Dong, Dalseogu, Daegu, Korea.

**FOR TRADE** — 10" f/4.5 Dobsonian, 9 pt. cell, 4-vane spider, new secondary, 8x50 finder. Will trade for a Meade 2045 or Bausch & Lomb 4000 (Prefer with piggy-back.) Must be within 500-mile radius of Oklahoma City, OK. Contact Mike Weatherby, 12810 Decker Drive, Jones, OK 73409. Phone (405) 399-9485 or (405) 732-1902.



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